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Ware River Intensive Watershed Study
2. Estuarine Receiving Water Quality

Virginia Inst. of Marine Science
Gloucester Point

Prepared for

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The Ware River is a relatively "clean" estuarine system. However, during summer months some of the nutrients, particularly inorganic phosphorus and organic nitrogen, achieve levels associated with moderate enrichment. The Ware is typical of other small tributaries of Chesapeake Bay: nutrient levels are higher at low tide, the estuary is more homogeneous laterally than longitudinally, and vertical gradients exist for dissolved oxygen, total phosphorus, and suspended solids.

The estuary is generally phosphorus limited, except during the annual spring phytoplankton blooms (April 1979 and March 1980) when uptake of inorganic nitrogen by plankton causes the system to be nitrogen limited.

Impacts of nonpoint source pollution are slight and shortlived in the estuary. This appears to be due to dilution by Bay waters and sedimentation in the upstream marshes. Thus, impacts typically are observed only in the shallow upstream portions of the estuary.

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WARE RIVER INTENSIVE WATERSHED STUDY
2. ESTUARINE RECEIVING WATER QUALITY

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Estuarine Studies

The Ware River is a relatively "clean" estuarine system. However, during summer months some of the nutrients, particularly inorganic phosphorous and organic nitrogen, achieve levels associated with moderate enrichment. The Ware is typical of other small tributaries of Chesapeake Bay: nutrient levels are higher at low tide, the estuary is more homogenous laterally than longitudinally, and vertical gradients exist for dissolved oxygen, total phosphorous, and suspended solids.

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SECTION 1

1.1 INTRODUCTION

The Ware River Study is one of five intensive watershed studies funded by the Chesapeake Bay Program of the U.S. Environmental Protection Agency. In all five basins small catchments are being monitored to determine the quantity and quality of runoff for the major land uses and physiographic features of the Chesapeake Bay drainage basin. These data will be used to calibrate mathematical models of land runoff which in turn will be used to determine the quantity of pollutants entering Chesapeake Bay from nonpoint sources and to examine how these loads are likely to vary as land uses change in the future. Results from the nonpoint source study are contained in a companion report, Ware River Intensive Watershed Study 1. Nonpoint Sources.

In the Ware system and in the two Maryland watersheds, estuarine water quality is being studied to determine how it is affected by runoff. The Ware River is relatively clean, and to a certain extent, it serves as the "control" against which more impacted systems can be compared. At the beginning of this study relatively little data was available on the Ware River; it was not polluted so it had not been the subject of extensive monitoring in the past. Therefore the Ware study included elements to characterize seasonal, tidal, diurnal and other variations so that the effects of stormwater runoff could be separated from other features. The information gained in this study will provide us with a better understanding of the nature, extent and duration of stormwater impacts on estuarine water quality. In addition, the field data will be used to calibrate a series of models which will simulate runoff generation and its transport through the streams and into the estuary.

Section 1, a synopsis of the report, contains a description of the study area and conclusions from the 27-month investigation. In the second section, details are presented on the hydrography and water quality of the receiving waters and the methods used in collecting the data. Section 2.2 discusses diurnal trends in the estuarine water quality from measurements made around-the-clock during intensive surveys, the first of which took place during the summer of 1979. Seasonal trends in estuarine water quality were studied by frequent high water slack surveys and is included in Section 2.3. The characteristics of the transition zone from the freshwater flowing streams to the tidally influenced, brackish waters of the estuary is also described in this section, along with impacts of stormwater upon the area. A number of incidental topics and findings are presented, including a discussion of quality control and a comparison of automatic vs. discrete water sampling techniques.

The remainder of the report includes references and a series of appendices containing supporting material. Sampling stations are described in Tables A-1 and A-2; the dates of the slackwater surveys are given in Table A-3. Since the focus of the field efforts varied, all stations were not occupied during each study. Table A-4 gives the station coverage for slackwater, intensive and stormwater runoff surveys.

1.2 DESCRIPTION OF THE STUDY AREA

The Ware River drainage basin lies on the Middle Peninsula of Virginia between the York and Rappahannock Rivers, as shown in Figure 1. The Ware, along with the Severn, North and East Rivers, debouches to Mobjack Bay on the southwestern shore of Chesapeake Bay. Beaverdam Swamp and Fox Mill Run are two freshwater tributaries which drain the upper reaches of the basin and provide nearly continuous flows to the estuary. In addition to the two main stems of the river, two small sub-basins drain into man-made impoundments, Cow Creek Pond and Robbins Pond, before discharging to the tidal waters of Beaverdam Swamp and Wilson Creek respectively. The freshwater streams generally are shallow (less than 1 meter deep) and not especially wide (usually less than 4 meters). The channels are sinuous, frequently braided and often interrupted by beaver dams, especially in the headwaters.

Tidal effects are observed at the Route 14 crossing of Beaverdam Swamp and just downstream of the Route 17-Business crossing of Fox Mill Run. In the transition zone the salinity gradients are large and the channels follow a serpentine course through extensive tidal marshes on either side of Deacon's Neck. The Ware proper is formed by the confluence of these two tidal streams at Warehouse Landing. The main channel of the estuary is broad and shallow and is approximately 9.6 km long. The river depth at Mean High Water varies from 8 meters at the mouth to less than 1.5 m near Warehouse Landing. The channel margins and subtidal flats are generally narrow, making up less than 20% of the river suface area. Salinities usually are 17-21 parts per thousand (ppt) at the mouth, and reflect the strong influence of Chesapeake Bay. Salinities at the confluence range between 6 and 17 ppt showing the influence of runoff.

The drainage area of the Ware is 174 square kilometers. Land use in the basin is rural, with over 70% of the land occupied by forests. Agriculture, primarily rowcrops with annual rotation of corn and soybeans, account for about 12% of the total land area. Residential and commercial uses occupy only about 7.2% of the basin; the majority of this development is at Gloucester Court House, located near the center of the watershed. The single point source in the basin, a sewage treatment plant serving Gloucester, dicharges to Fox Mill Run approximately 570,000 liters per day of secondary effluent about a half kilometer above the tidal reaches.

The freshwater discharge entering the Ware River is small relative to the volume of the estuary. The long term average discharge at the USGS gaging station near Ark, Va. on Beaverdam Swamp is 0.21 cubic meters per second. The average annual rainfall is 111 cm based on a thirty year record for 27 gages in

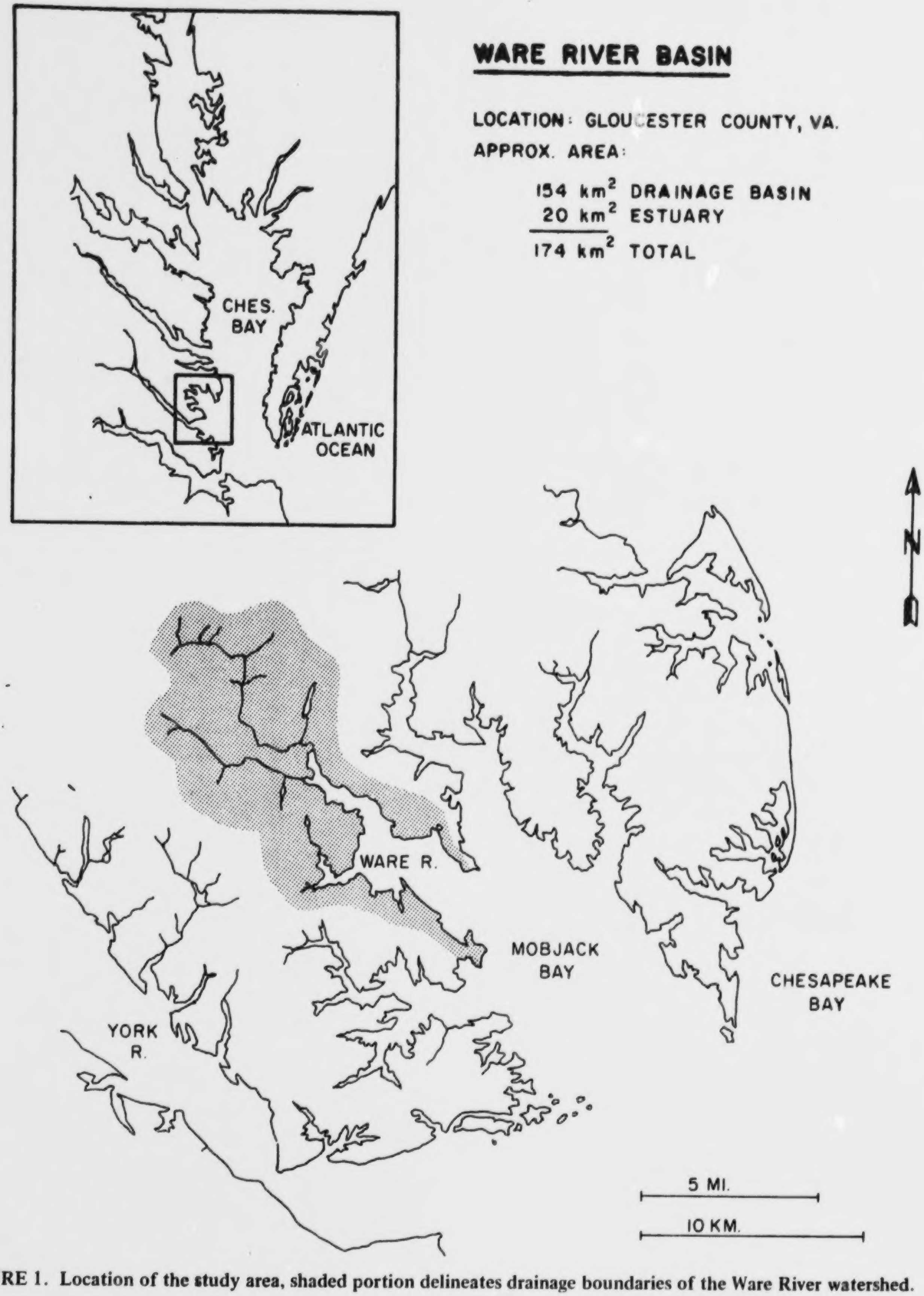

WARE RIVER BASIN
LOCATION: GLOUCESTER COUNTY, VA.
APPROX. AREA:
154 km² DRAINAGE BASIN
20 km² ESTUARY
174 km² TOTAL
CHES. BAY
ATLANTIC OCEAN
N
WARE R.
MOBJACK BAY
CHESAPEAKE BAY
YORK R.
5 MI.
10 KM.

FIGURE 1. Location of the study area, shaded portion delineates drainage boundaries of the Ware River watershed.

Virginia's coastal plain (U.S. Environmental Data Service, 1979). Monthly average rainfall is fairly uniform and ranges from about 7 cm in April to nearly 12 cm in July. Although rainfall is high during summer months, monthly mean discharges are lowest then, presumably due to high rates of evaporation and transpiration. Meteorological conditions during the study have been somewhat anomalous. In general 1979 was a wet year and 1980-1981 was dry. Also the snowfall during the first winter was exceptionally high for this area and was greater than any since records have been kept. Although both total rainfall and stream discharge for 1979 were high (see Figure 39), the rainfall was unevenly distributed throughout the year. For example, the rainfall during September and November 1979 was the highest for the years 1966 through 1979, while the rainfall for December 1979 was the lowest for that month during the same period. Additionally, during the first 14 months there was a 33.4 cm surplus of rainfall compared to the average of 128.8 cm expected for Tidewater (based on data 1940-1970), while during the latter 13 months there was a 37.8 cm deficit in rainfall. As a result of the draught, Beaverdam Swamp reached zero discharge in late July 1981, the first time this has occurred since 1953 (USGS, 1981).

1.3 CONCLUSIONS

Results from the 27-month study showed water quality in the Ware River to be relatively non-degraded. The broad reaches of the estuary are dominated by Chesapeake Bay waters and are rather homogeneous laterally and longitudinally. However, upstream in the narrow tidal marsh regions, nutrient rich conditions exist, and concentrations generally decrease with distance downstream, indicating that advective diffusion plays a major role in determining overall water quality. The estuary is generally phosphorus limited, except on a few occassions and in a few locations. For example, during the annual spring phytoplankton blooms, uptake of inorganic nitrogen by plankton causes the system to become nitrogen limited. Also, Fox Mill Run, the only tributary containing a point-source (57,000 liter per day secondary sewage treatment plant) contains elevated nutrient concentrations and is nitrogen limited year round due to the effects of phosphorus rich sewage.

The Ware River is typical of many shallow subestuaries that drain the coastal plain. During low flow conditions, freshwater inputs to the estuary are insignificant. During high flow conditions, vertical stratification may exist in the downstream portion of the estuary, but the gradient is not strong (<2 ppt salinity). The freshwater to saltwater interface shifts over several kilometers in the narrow upstream reaches in response to freshwater inputs, and a turbidity maximum was found to exist in at least one of the tributaries, Beaverdam Swamp.

Distinct seasonal patterns were evident: nutrient concentrations for total phosphorus and nitrogen concentrations in the estuary were greatest during the summer season; dissolved oxygen levels were lowest at that time. Results from the trend data also suggested that increased nutrient concentrations in the spring and fall were generally due to runoff contributions, and inputs in the form of marsh debris. During the summer, or times of low flow and high temperature, nutrient cycling and release from the sediments appeared to be the primary factor controlling nutrient levels.

Chlorophyll-a exhibited a spring maximum, especially during 1979 and 1980. Phytoplankton cell counts showed diatoms to be the dominant spring organism (primarily *Rhizosolenia* and *Nitzschia*). During the spring of 1981, the typical chlorophyll-a maximum was not observed. This was presumably due to the drought conditions which resulted in lesser amounts of dissolved silica introduced into the estuary from baseflow.

Assessment of stormwater impacts in the estuary revealed that rainfall of 0.5 in (1.3 cm) or more resulted in measurable changes in estuarine water quality. Suspended solids and nitrite+nitrate nitrogen concentrations increased, whereas dissolved oxygen (measured as percent saturation) tended to decrease following major storms. The extent and duration of nonpoint source pollution varied greatly dependent upon the amount and intensity of rainfall, and time of year. Generally, responses in the estuary were short-lived; nutrient loadings were offset by dilution upon entering the broad reaches of the estuary.

SECTION 2. ESTUARINE FIELD STUDY AND RESULTS

The Ware River is typical of other small estuaries that drain the coastal plain. Low density residential housing peppers the shoreline. Because of the dearth of population and industry along the river, many of the well-known environmental problems of pollution are absent. Since the Ware River is a fairly "clean" estuary, it is a good system in which to assess the impacts of nonpoint source (NPS) pollution upon the water quality of an estuary. To accomplish this, it was necessary to ascertain the existing regime of nutrients through determination of descriptive norms and causal relationships. A baseline was established initially by conducting a series of semi-monthly highwater slack (HWS) surveys. Such information serves as a reference to which perturbations in the nutrient levels can be compared.

The effects of nonpoint source pollution, the particulate matter and associated nutrients that are in runoff from the land, may play an important role in the productivity of small coastal plain estuaries. The significance of increased nutrient levels upon the receiving waters has been discussed by many authors (Ketchum, 1967; see also Neilson, 1980). Few other studies have attempted to address nutrient levels in the Ware River estuary. The Virginia State Water Control Board (SWCB) has routinely monitored one of the tributaries, Foxmill Run, for fecal coliforms, various nutrients, dissolved oxygen, pH and alkalinity since wastewater is discharged into the stream.

In April, 1979, the Department of Estuarine Processes of the Virginia Institute of Marine Science, College of William and Mary, initiated a two year investigation of the Ware River watershed, funded by the Environmental Protection Agency's Chesapeake Bay Program. The primary objectives of the estuarine research effort were to provide a description of the hydrography and water quality and to ascertain the temporal and spatial response of the estuary to runoff. The results of the estuarine monitoring will be presented in terms of trends, in particular seasonal patterns, and intensive surveys, which were conducted to define spatial distribution of nutrients as well as solar, tidal and other diel processes in the estuary. The estuarine response to runoff, especially the variations which occur in the freshwater to saltwater transition zone, are discussed in Section 2.

2.1 METHODS AND MATERIALS FOR ESTUARINE FIELD SAMPLING

Sampling stations (Figure 2) were established in the Ware River, first, on the basis of the probable value of the hydrographic and water chemistry information they would provide, and second, on the ease of access to the area since the estuary is extremely shallow in the upper reaches. Stations were located by means of buoys, markers and sitings off landmarks.

Surveys were conducted with 18 1/2' T-Birds outfitted with either single or twin outboard engines. Water was pumped onboard using a Rule Bilge Pump (750 GPH), and bottles were filled according to the schedule below once the lines had been cleared at each station. In case of pump failure, samples were collected using a Frautschy bottle (a modified Van Dorn discrete water sampler).

DO: 125 ml glass bottles

SALINITY: 125 ml glass bottles

NURIENTS: 2L Nalgene containers

pH/ALKALINITY/SS: 500 ml brown Nalgene bottles

CHLOROPHYLL: 250 ml brown Nalgene bottles

BOD5: 300 ml glass BOD bottles

UBOD: 2L Nalgene containers

The field program in the freshwater portions of the estuary involved little mechanical equipment; all equipment was serviced and calibrated before field usage. Field sampling techniques were selected to insure representative sampling.

Temperatures measurements in the water column were taken using an Applied Research Austin (ARA) Model ET 100 Marine temperature sensor. Accuracy of the instrument is reported to be 0.1 C. The instrument was tested and recalibrated, when necessary, before each survey. Dissolved oxygen samples were "pickled" in the field (manganese sulfate solution followed by alkali-iodide azide reagent) and titrated in the laboratory using the azide modification of the Winkler method.

A list of chemical parameters, methods of analysis, and STORET numbers for each variable are listed in Volume 1. *Nonpoint Sources*.

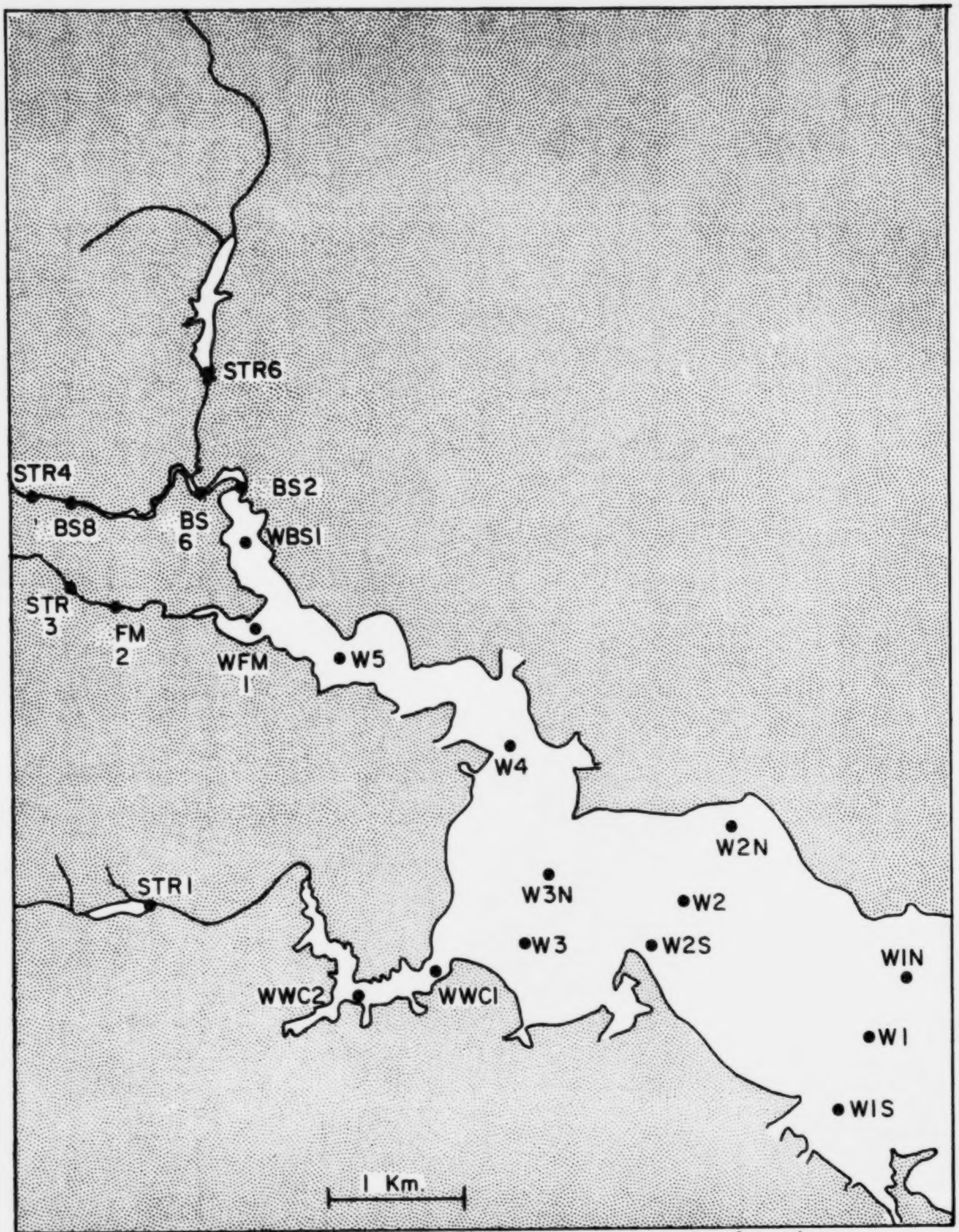

STR6
STR4
BS2
BS8
BS 6
WBS1
STR 3
FM 2
WFM 1
W5
W4
W2N
W3N
W2
STR1
W3
W2S
WIN
WWC2
WWC1
W1
W1S
1 Km.

Figure 2. Ware River estuarine and freshwater stream station locations.

2.1.1 ESTUARINE HYDROGRAPHIC DATA COLLECTION

Bathymetric data was obtained along 15 different transects in the Ware River during 1979-1980 using a Raytheon fathometer (see Appendix A-5). Cross-sectional areas are listed in Appendix A-6.

Current Meter Information

General Oceanic current meters (recording at 6 min intervals for a minimum of 8 tidal cycles) were deployed in the Ware River estuary in August, 1979 and July, 1980. During the first year, lateral as well as longitudinal and vertical data was collected. Information collected indicated that water movement was fairly uniform across the channel, therefore during the second year, all current meters were placed in the center of the channel but spanned a greater longitudinal distance.

Tide Gage Information

Two tide gages were installed on piers in the Ware River at rivermile 1.3 and 5.3. Tide gage information was recorded concomitant with current meter recordings. Results indicated that 1). there was an average tidal range of 0.76 m at the downstream gage, and 2). high tide occurs approximately 35 minutes after the times reported for Hampton Roads (Sewell's Point) by the U.S. Department of Commerce, National Oceanic and Atmospheric Administration. However, a variance of 71 minutes was found, depending on wind conditions and other factors. Tidal information for 1979 and 1980 has been recorded on magnetic tape and forwarded to SWCB.

2.1.2 OTHER SPECIAL ESTUARINE SAMPLING EQUIPMENT

PLANKTON ANALYSES

Zooplankton and phytoplankton were collected seasonally from at least three of the slackwater stations located in the main channel of the estuary.

Phytoplankton:

Phytoplankton samples were pumped into 2-liter plastic containers and placed on ice until brought to the laboratory for analysis.

Phytoplankton samples were first examined and enumerated with an epi-fluorescent microscope using a proflavin-modified Acridine-orange direct count method (Hobbie, et al., 1977; Watson, et al., 1977) and categorized by percentages into major groups (blue-green algae, cryptomonads, prasinophytes, heteroflagellates, green flagellates, dinoflagellates, diatoms and miscellaneous).

Carbon content determinations were then obtained from the phytoplankton samples using dry and ash-free weight measurements according to the procedures outlined in Standard Methods (APHA, 1975) and in the EPA Biological Field and Laboratory Methods (U.S. EPA, 1979).

Zooplankton:

Zooplankton were collected in a Clarke-Bumpus sampler using a #20 mesh (76 u) net. At each station a minimum of 200 liters of water were towed through. Samples were taken throughout the water column (oblique samples) with equal towing time at each depth. Samples were placed on ice for transport to the laboratory where biomass (carbon-content) determinations were performed as described for phytoplankton above.

PARTICLE SIZE DISTRIBUTION

Particle size distribution samples were taken seasonally at all estuarine stations using a modified-clam bottom grab. Samples were analyzed for total (undigested) and inorganic (digested) particle sizes on a TA-2 Coulter Counter with population assessor. Organic values were obtained through calculation.

BED SEDIMENT ANALYSES

Bed sediments were sampled seasonally at all estuarine stations; samples were analyzed for total and inorganic carbon using an induction furnance and gasometric carbon analyzer manufactured by the Leco Corporation. Organic carbon values were obtained through calculations. Total sulfur analyses were also run on samples using the Leco induction furnance.

SEDIMENT OXYGEN DEMAND

The apparatus used for determining sediment oxygen demand consisted of a cylindrical chamber fitted with a self-contained battery-powered stirrer and a dissolved oxygen probe (YSI-15) plugged into the top of the chamber. The chamber was open at the bottom and weighted so that it settled into the sediment and effectively isolate a unit bottom area and a parcel of overlying water. The stirrer provided gentle agitation to keep water moving past the membrane on the probe without stirring up the sediment. The dissolved oxygen concentration of the trapped water parcel was monitored for a sufficient length of time to obtain a dissolved oxygen versus time slope (m). The bottom oxygen demand was calculated according to the following formula:

$$\mathrm{SOD}\ \frac{\mathrm{gm\ oxygen}}{\mathrm{m}^2 \cdot \mathrm{day}} = \frac{m \left(\frac{\mathrm{mg\ oxygen}}{\mathrm{L} \cdot \mathrm{hr}} \right)}{10^2} \cdot H \cdot 24$$

where H is the mean depth of the chamber in cm allowing for the volume displaced by the stirrer.

SECTION 2.1.3 STATISTICAL METHODS

Statistical methods used consisted of 1) means and other descriptive statistics, 2) correlation analysis, 3) analysis of variance, and 4) Duncan's Multiple Range Test (Sokal and Rohlf, 1969). A brief description of Duncan's Multiple Range Test follows for readers not familar with the analysis.

Duncan's Multiple Range Test was used to calculate means for each variable (in this case specific nutrient parameters) by station. The group means for each variable are then arranged in order from largest to smallest. The test is performed for each variable using the error mean square, error degrees of freedom and the F-value specified (a=0.05 unless otherwise specified in this report). If one of the station variables is missing, then the observations at all stations at that time are deleted from the analysis. Means that are not significantly different from one another can then be grouped.

Notably, this is a crude test; it does not have provisions for time series analysis, although most intercompared samples were collected within 30 minutes of one another during the Intensive Surveys and within 2 hours during HWS surveys. Secondly, some nutrient concentrations fall below laboratory analytical detection limits. In such cases, a value that is half the detection limit was used for calculating means, since it was felt that this value would be more representative than either the lowest standard value or a zero value.

2.1.4 QUALITY CONTROL DATA

During the 1980 and 1981 Intensive Surveys, 5 replicate samples were collected simultaneously at several stations in the estuary for each parameter. The mean, standard deviation and variance were calculated and results are presented in Table 1.

Results showed good overall quality control; standard deviation and variance were very low. It should be noted, however, that alkalinity, suspended solids and chlorophyll-a measurements, in some cases, differed by one standard deviation unit.

Table 1. Quality Control Information.*

1980

STATION=WFM1

VARIABLE	MEAN	STANDARD DEVIATION	VARIANCE
SAL	16.86	0.09	0.01
DO	5.76	0.08	0.01
SS	16.20	3.42	11.70
BOD5I	1.42	0.24	0.06
CHLOR	8.04	0.60	0.36
PHEO	5.56	0.44	0.20
SILICA	2.66	0.05	0.00

VARIABLE	MEAN	STANDARD DEVIATION	VARIANCE
PH	7.52	0.02	0.00
ALK	86.00	0.23	0.06
OPF	0.01	0.01	0.00
TP	0.10	0.01	0.00
TKN	0.71	0.04	0.00
NH3	0.00	0.00	0.00
NH3F	0.00	0.01	0.00
NO2	0.00	0.00	0.00
NO2NO3	0.00	0.00	0.00

STATION=W2T

VARIABLE	MEAN	STANDARD DEVIATION	VARIANCE
SAL	18.48	0.04	0.00
DO	6.53	0.29	0.08
SS	9.00	4.24	18.00
BOD5I	1.35	0.24	0.06
CHLOR	8.52	1.18	1.40
PHEO	2.92	0.37	0.14
SILICA	2.33	0.01	0.00

VARIABLE	MEAN	STANDARD DEVIATION	VARIANCE
PH	7.84	0.12	0.01
ALK	78.60	1.47	2.16
OPF	0.00	0.01	0.00
TP	0.05	0.00	0.00
TKN	0.59	0.02	0.00
NH3	0.00	0.00	0.00
NH3F	0.00	0.00	0.00
NO2	0.00	0.00	0.00
NO2NO3	0.00	0.00	0.00

1981

STATION=WBS1

VARIABLE	MEAN	STANDARD DEVIATION	VARIANCE
SAL	21.30	0.00	0.00
DO	8.60	0.16	0.02
SS	10.00	0.35	0.13
BOD5I	1.41	0.10	0.01
CHLOR	0.70	0.25	0.07
PHEO	1.12	0.35	0.12
SILICA	0.26	0.08	0.01

STATION=WFM1 --

VARIABLE	MEAN	STANDARD DEVIATION	VARIANCE
SAL	21.96	0.36	0.13
DO	9.50	0.06	0.00
SS	17.20	7.97	63.45
BOD5I	1.32	0.11	0.01
CHLOR	1.22	0.22	0.05
PHEO	1.02	0.19	0.04
SILICA	0.16	0.03	0.00

STATION=W5 --

VARIABLE	MEAN	STANDARD DEVIATION	VARIANCE
SAL	22.70	0.00	0.00
DO	9.82	0.08	0.01
SS	3.10	2.88	8.30
BOD5I	1.59	0.24	0.06
CHLOR	1.66	0.21	0.04
PHEO	0.42	0.04	0.00
SILICA	0.10	0.01	0.00

STATION=WBS1

VARIABLE	MEAN	STANDARD DEVIATION	VARIANCE
PH	7.70	0.06	0.00
ALK	87.72	0.89	0.79
OPF	0.00	0.00	0.00
TP	0.04	0.02	0.00
TKN	0.43	0.02	0.00
TKNF	0.33	0.03	0.00
NH3F	0.03	0.00	0.00
NO2	0.00	0.00	0.00
NO2NO3	0.04	0.01	0.00

STATION=WFM1 --

VARIABLE	MEAN	STANDARD DEVIATION	VARIANCE
PH	7.84	0.04	0.00
ALK	88.72	1.15	1.33
OPF	0.00	0.00	0.00
TP	0.04	0.02	0.00
TKN	0.39	0.01	0.00
TKNF	0.30	0.02	0.00
NH3F	0.01	0.01	0.00
NO2	0.00	0.00	0.00
NO2NO3	0.02	0.00	0.00

STATION=W5 --

VARIABLE	MEAN	STANDARD DEVIATION	VARIANCE
PH	7.91	0.03	0.00
ALK	89.38	1.01	1.03
OPF	0.00	0.00	0.00
TP	0.02	0.01	0.00
TKN	0.36	0.02	0.00
TKNF	0.29	0.03	0.00
NH3F	0.02	0.05	0.00
NO2	0.00	0.00	0.00
NO2NO3	0.00	0.00	0.00

* Sample size (n) = 5 in all cases above.

2.2.1 1979 INTENSIVE SURVEY

On August 14 and 15, 1979 an intensive survey was conducted on the Ware River to provide a comprehensive picture of how water quality changes temporally and spatially in response to sunlight and tidal oscillation. Seventeen stations in the estuary, four freshwater stream sites and the Gloucester sewage treatment plant, the single point-source discharge into the estuary, were monitored round-the-clock for slightly over two cycles (27 hours).

Temperature, salinity and dissolved oxygen were measured hourly, while samples for nutrients, chlorophyll-a, pH, alkalinity, carbonaceous 5-day biochemical oxygen demand (BOD) and suspended solids were collected every 3 hours. A set of ultimate oxygen demand determinations was made once at HWS throughout the estuary. Ancillary studies such as enumeration of nitrifying bacteria, sediment oxygen demand measurements, plankton biomass determinations and identification of major phytoplankton groups were conducted as well.

Two tide gages and 7 current meters were deployed to provide hydrographic information. Cross-channel bathymetries also were taken along each station transect.

Water temperatures during the survey ranged from 25.4 C to 29 C. Similarly pH was homogeneous throughout the estuary ranging from 7.3 - 7.9. Skies were clear on the 14th, air temperatures ranged from 20 - 29 C (68 - 84 F) and winds were out of the west 16 - 32 km/hr (10 -20 mph). On the 15th the skies were overcast, air temperatures ranged from 20 - 25 C (68 - 77 F), winds were calm, out of the north at 5 km/hr (3 mph).

Salinity

The Ware River is a mesohaline estuary and subject to freshwater flow fluctuations. During the first intensive, a relatively "wet" year, salinities ranged from about 17 ppt at the river mouth to 10 ppt at Warehouse Landing, the confluence of Beaverdam Swamp and Fox Mill Run. Temporal variation of salinity showed a strong tidal periodicity, with greatest variation upstream (see Figure 3). Amplitude of tidal variation in salinity increased with distance from the river mouth, with range of variation reaching as high as 6.6 ppt at the upstream stations. The longitudinal salinity gradient in the downstream portion of the estuary was slight, less than 0.12 ppt per km at the mouth and about 0.5 ppt per km in the mid-reach of the estuary. At the landing the gradient was very large at low water slack, on the order of 3 or more ppt per km.

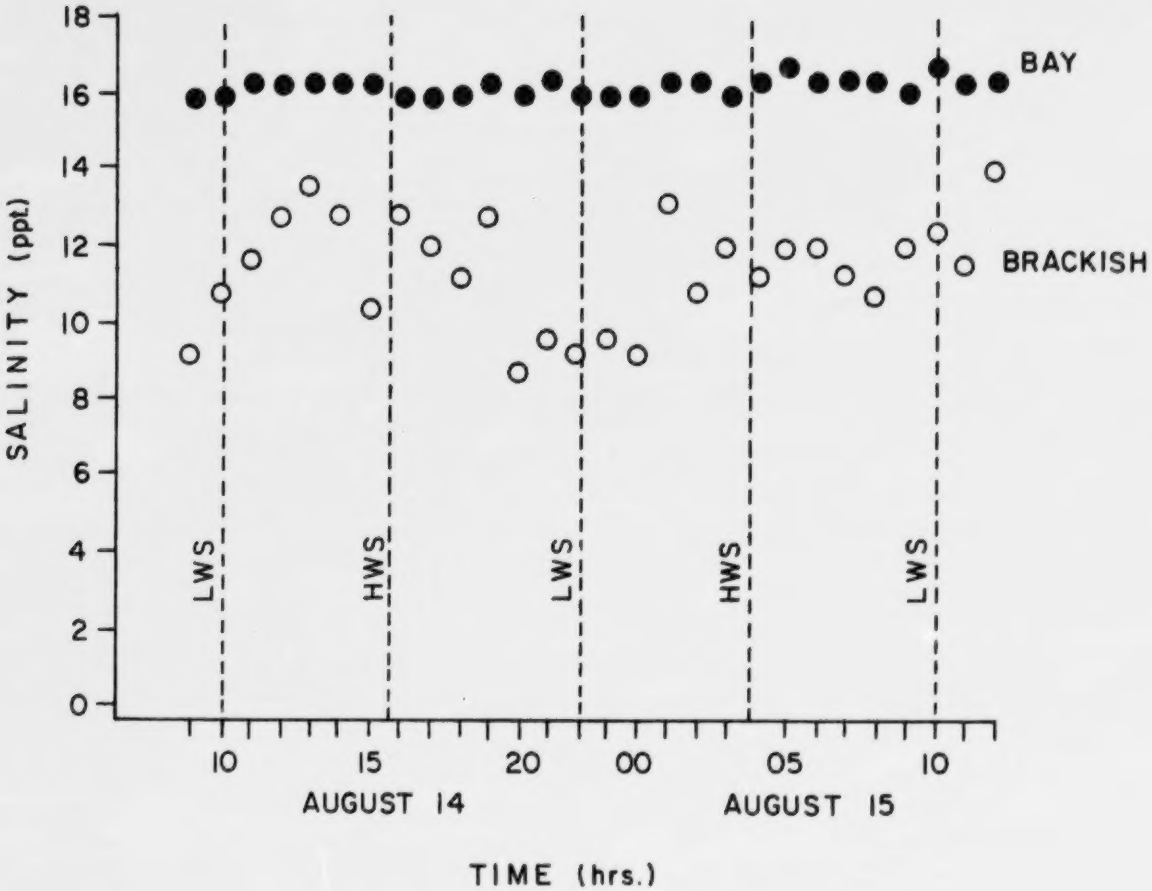


FIGURE 3. Tidal variation in salinity during the August 14-15, 1979

The 27 hour intensive survey was conducted at a time of neaptides, a period of maximum water column stability (Haas, 1977). Significant stratification, defined as a salinity difference greater than 1 ppt between top and bottom stations, occurred only at the two most downstream stations, W1 and W2, and only during parts of the tidal cycle (Table 2). This indicates that tidal mixing dominates and that the estuary is essentially well-mixed, especially in the upstream reaches (Cameron and Pritchard, 1965). The lack of stratification of the water column at this time is probably due to 1) the shallow nature of the estuary, 2) the proximity of sampling to the spring tide turnover and 3) the westerly winds which would tend to further mix the water column.

Dissolved Oxygen

Temporal variations in dissolved oxygen were greatest at the upstream (brackish) stations where concentrations ranged between 4.5 and 10.25 mg/l. Oxygen concentrations were highest in mid-afternoon and lowest just prior to sunrise. Due to the clear weather and the fact that summer days are longer than nights, oxygen concentrations near the surface exceeded saturation values, as the plankton and benthic communities typically produced more oxygen than they consumed. The maximum saturation value (128%) was recorded of WFM1 at 1414 hours.

During the 27 hour sampling period, all of the estuarine stations had mean oxygen values greater than 4.0 mg/l. Lowest values were found in the deepest waters (7 m) which might be attributed to sediment oxygen demand; sediment oxygen demand measurements taken at the mouth one week prior to the Intensive Survey, indicated a benthal uptake of 1.4 gm/m2/day, or slightly greater than the normal demand present in estuaries of 1 gm/m2/day (Edwards, 1965).

Chlorophyll-a

In this study chlorophyll-a was utilized as a measure of suspended plant biomass. Values were within the range normally found in estuarine waters and considerably below values associated with nutrient enriched conditions. The highest values recorded (16 ug/l) were for a station at the mouth of the estuary (W1T). Chlorophyll-a values also tended to be elevated at the upstream sites (W5). Temporal variations were observed throughout the estuary. Diel variations were greatest at the mouth with values ranging from 16 to 1.9 ug/l. Throughout the estuary, daytime values were roughly twice nighttime values; diurnal variations appeared to be correlated more with sunlight than tidal stage. This is perhaps another indication that the Ware is relatively clean, since instances where chlorophyll-a levels do vary significantly with tidal stage appear to ocur mostly in highly enriched estuaries (Welch and Isaac, 1967; Rosenbaum and Neilson 1977).

TABLE 2. Salinity Differences between surface and bottom samples during Intensive Survey of the Ware River, August 14-15, 1979

hour		W3 ΔS (ppt)	W2 ΔS (ppt)	W1 ΔS (ppt)
0900		0.18	0.14	1.05*
1000	LWS	-0.01	-0.02	.57
1100		-0.02	0.03	-1.04*
1200		-0.03	-0.03	1.51*
1300		-0.01	0.01	0.06
1400		-0.17	0.04	0.00
1500	HWS	-0.14	0.04	0.95
1600		0.01	0.01	1.32*
1700		.	0.05	0.74
1800		.	0.21	1.39*
1900		0.0	-1.31*	0.16
2000		0.09	-1.41*	0.04
2100		0.32	-0.06	0.18
2200	LWS	0.31	-0.88	1.77*
2300		0.48	0.82	1.63*
0000		0.34	1.70*	1.44*
0100		0.97	0.01	-0.23
0200		1.36*	1.31*	0.49
0300	HWS	0.82	1.52*	1.52*
0400		0.20	0.40	0.02
0500		-0.03	1.40*	0.90
0600		0.88	1.40*	1.62*
0700		-0.03	-0.68	1.16*
0800		-0.07	-0.07	1.18*
0900		0.17	1.45*	1.75*
1000	LWS	-0.01	-0.08	0.04
1100		-0.03	-0.42	1.26*
	Σ	6.68	15.50	24.02
	n	25	27	27
	$\bar{X}$	.27	.57	.89
	std. dev.	.36	.62	.62
	var.	.13	.37	.37

* Times of water column stratification

Since there was no monotonic longitudinal trend of chlorophyll-a concentration, this suggests that there might be separate pools of phytoplankton within the estuary. Physical/chemical conditions such as light and temperature are fairly uniform throughout the estuary. Therefore, the patchy distribution of phytoplankton is probably due to salinity gradients, advective effects of wind or water transport, nutrient availability as in proximity to the marsh area, or to population differences such as growth, mortality, sinking and migration rates of individual plankters and their grazers.

Nutrient and Suspended Solids Data

Temporal variations in nutrient concentrations were seen in the brackish region of the estuary within a tidal period. Maximum values for total Kjeldahl nitrogen, ammonia nitrogen, and total phosphorus occurred at times of low water slack; minimum values occurred at high water slack (Figures 4-6). However, nutrient water quality at the mouth fluctuated little with the tides. Nitrite+nitrate nitrogen concentrations were generally below detection limit throughout the estuary during the survey; 71% of the samples were less than 0.05 mg/l. As a result, detection limits were lowered to 0.01 mg/l to provide more information, since this nutrient is important in relation to phytoplankton growth.

Suspended solids (SS) showed no regular pattern through the 27 hours, especially at the mouth. Overall, concentrations were highest in bottom waters, which would be expected since sediments will setttle from the surface waters and become more concentrated near the bottom. In the brackish region, increased solids concentrations appeared to be, in part, a function of incoming Bay water (Figure 7), since denser, more saline bottom water carries suspended particulates in a net upstream current direction.

Lateral and Longitudinal Variations

The 1979 intensive survey was conducted not only to determine diel influences in water quality but also to delineate lateral and longitudinal variations that might exist in the estuary.

Five stations, W1N, W1S, W2N, W2S, W3N, (see Appendix A-2 for station locations and descriptions) additional to the slackwater stations were sampled in the estuary to determine whether cross-channel variations existed along a given transect. Samples were taken at mid-depth, and water quality parameters for all stations located on a transect were compared. Results were analyzed graphically and statistically, using Duncan's Multiple Range Test to check for significant differences among groups.

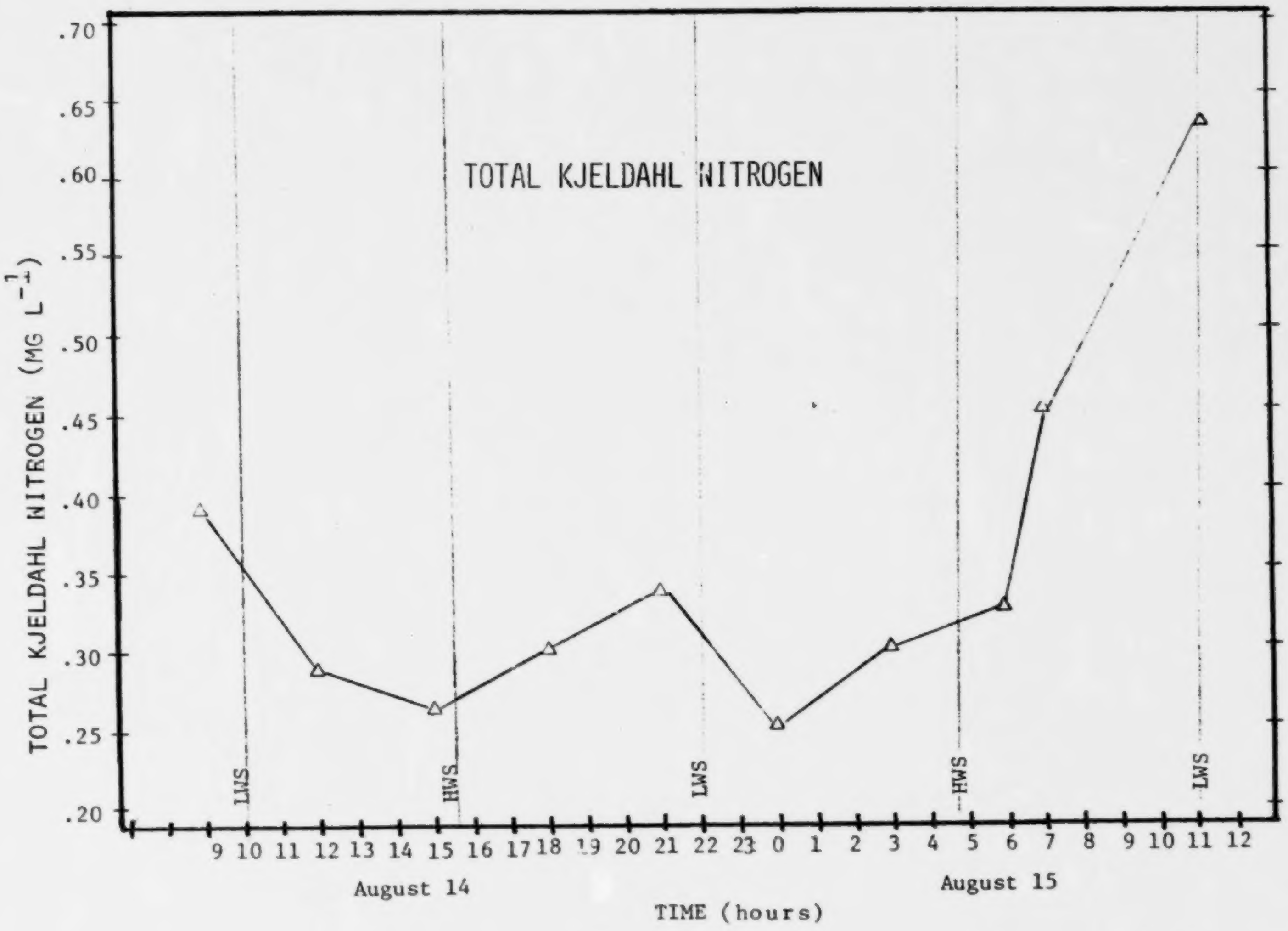


FIGURE 4. Average total Kjeldahl nitrogen concentrations in the brackish region (W5, WFM1, WBS1), August 1979 Intensive Survey.

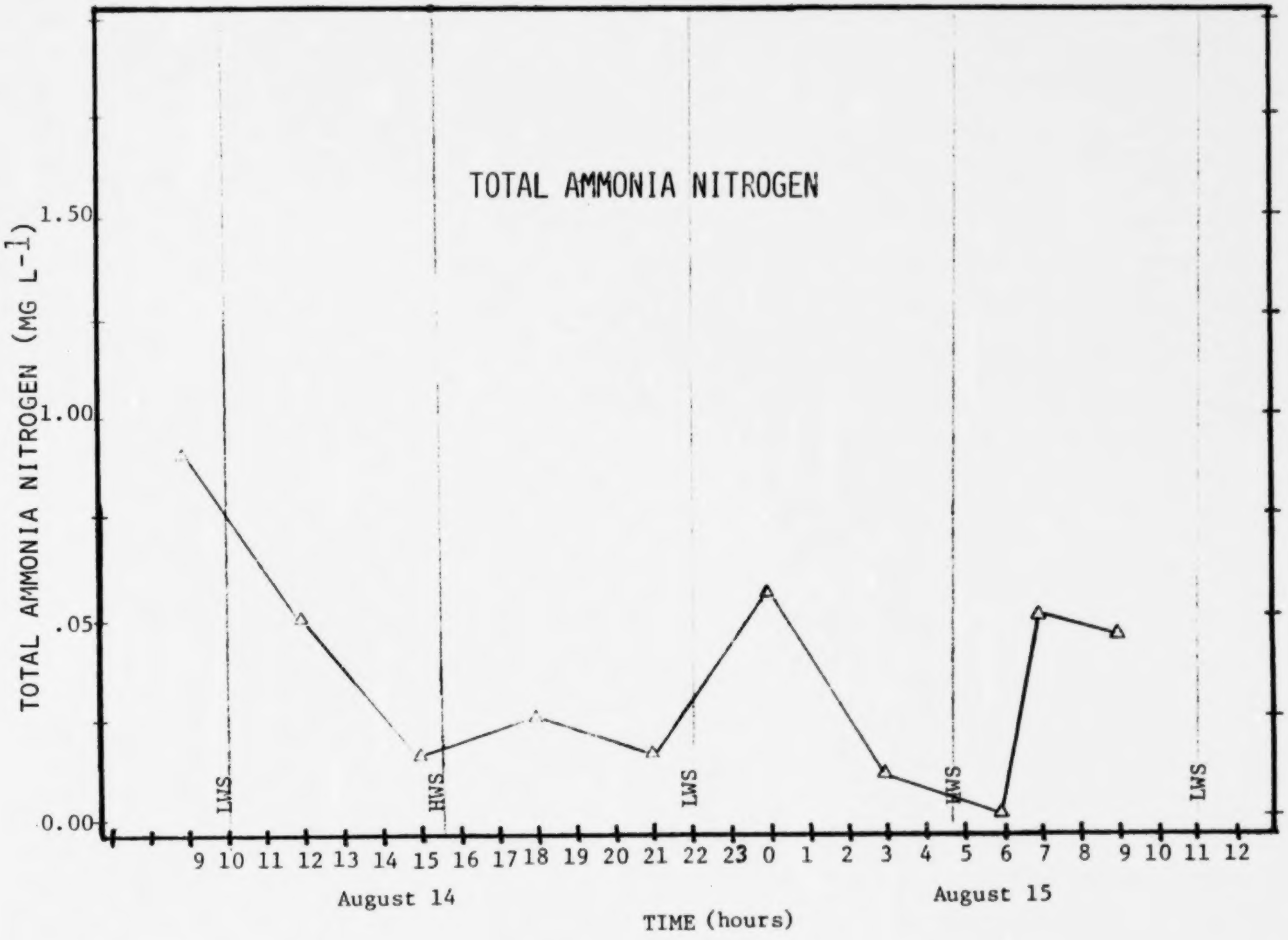


FIGURE 5. Average total ammonia-nitrogen concentrations in the brackish region (W5, WFM1, WBS1), August 1979 Intensive Survey.

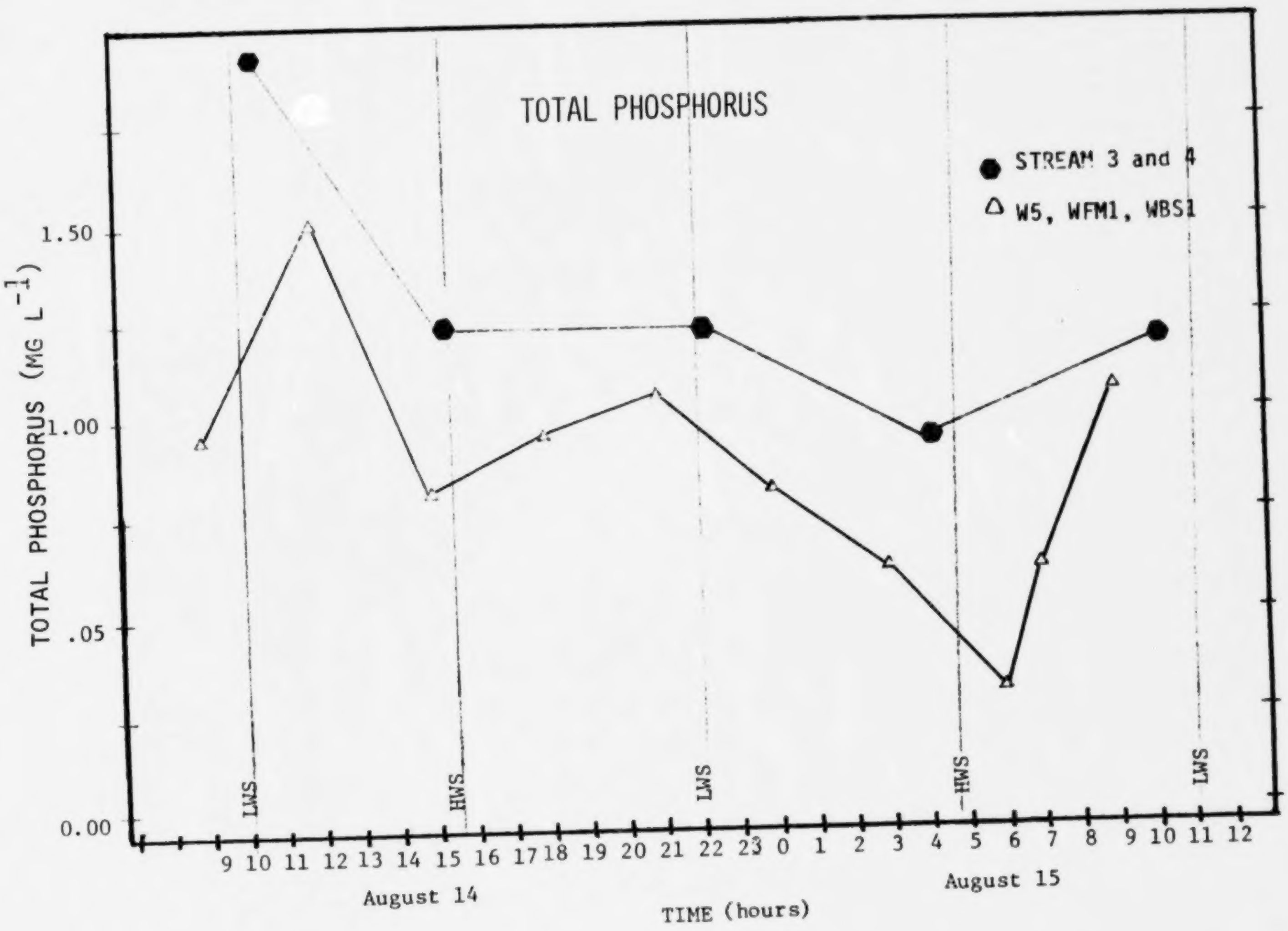


FIGURE 6. Average total phosphorus concentrations in the brackish region (W5, WFM1, WBS1), and stream sites (STR3, STR4), August 1979 Intensive Survey.

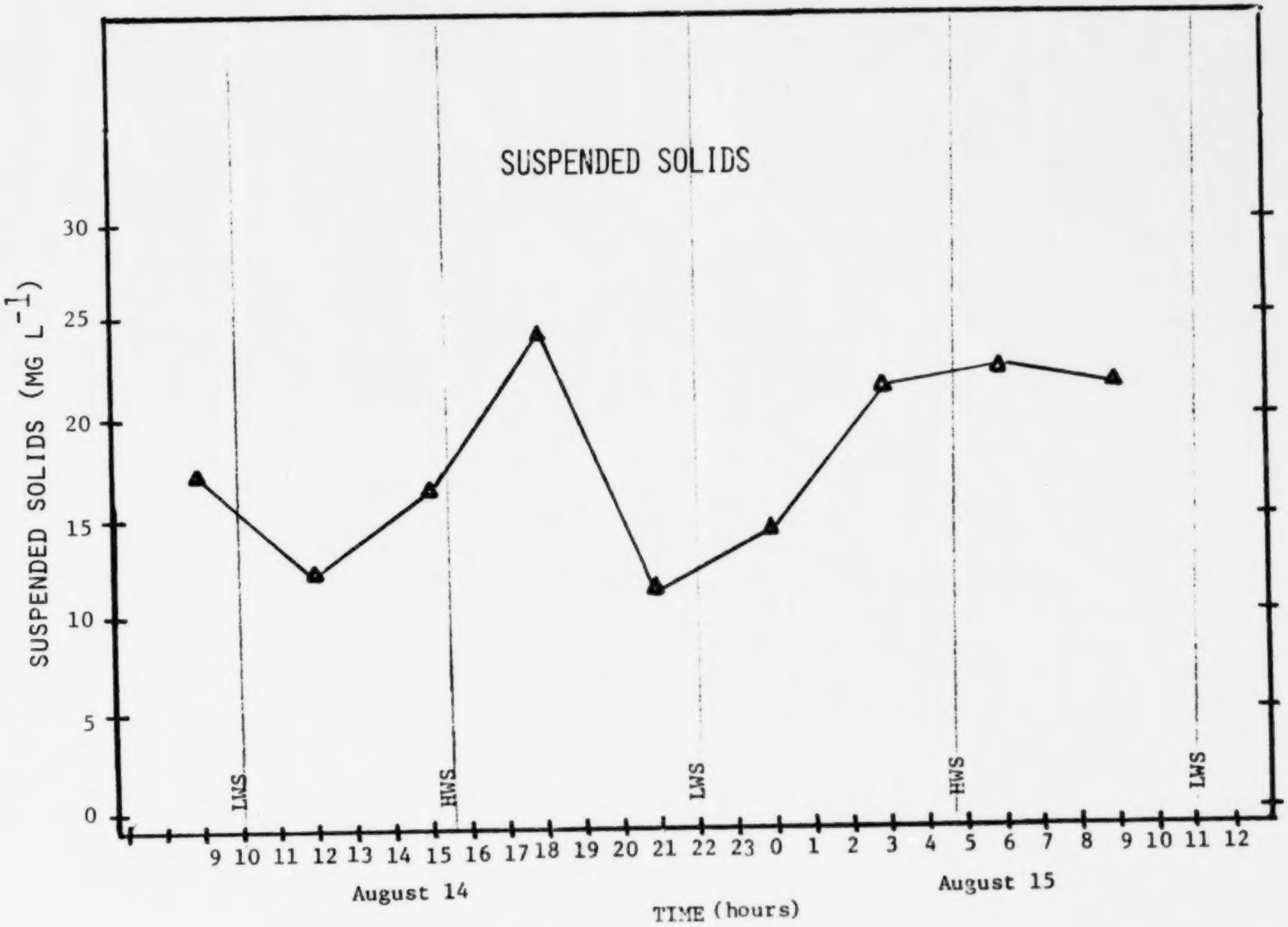


FIGURE 7. Average suspended solids concentrations in the brackish region (W5, (WFM1, WBS1), August 1979 Intensive Survey.

Longitudinal variations

Significant differences were found in station means for salinity which ranged from 17 ppt at the mouth to 10 ppt in the brackish area (W5, WBS1, WFM1). This salinity difference of 7 ppt was twice as large as the 3 ppt (average) longitudinal variation found over the 27-month study. Hence, the survey results can be used to delineate diel variations during a "wet" year. Average temperatures were fairly homogeneous throughout the main stem of the estuary during the study: at no time did temperatures range more than 4 C between stations. No significant longitudinal differences were found in levels for ammonia, dissolved ammonia, total Kjeldahl nitrogen, inorganic nitrogen and organic nitrogen. Chlorophyll- a means varied by only 4.8 ug/l at a given hour, from a maximum of 9.9 upstream (WBS1) to 5.1 ug/l near the mouth (W2). Significant differences, however, were found in total phosphorus and dissolved oxygen percent saturation. Highest oxygen levels were found at W5 and lowest at W1B. Concentrations of total phosphorus varied throughout the estuary, with highest concentrations in the brackish regions (W5, WBS1, WFM1) and lowest values downstream (W1S).

Lateral variations

Individual transects were analyzed for significant differences between station means. Analyses were conducted both with and without the bottom station in order to avoid skewing the significance testing for certain parameters (e.g., dissolved oxygen, salinity, total phosphorus) where large differences can exist in the water column.

Results from the Duncan's Multiple Range Test indicated no significant difference between sample means along any of the transects for total Kjeldahl nitrogen, organic nitrogen and ammonia nitrogen. Similarly, percent oxygen saturation was homogenous along the first two downstream transects, W1 and W2. Percent oxygen saturation was significantly different across transect W3; the percent oxygen saturation in the channel margins averaged about 10% above that in the main stem and appeared to vary with tidal stage (Figure 8). Likewise percent oxygen saturation was significantly different (a=0.05) between top and bottom station means at all transects.

Total phosphorus concentrations were predominantly below detection limit in the downstream waters (65% of the samples were less than 0.05 mg/l) and thus not suitable for this test. Of 143 measurable observations of 423 samples, concentrations were higher in the bottom waters.

Differences in salinity amounted to less than 2 ppt among the stations along a transect. This also tends to indicate that stratification was not present since top and bottom samples on a given transect varied little.

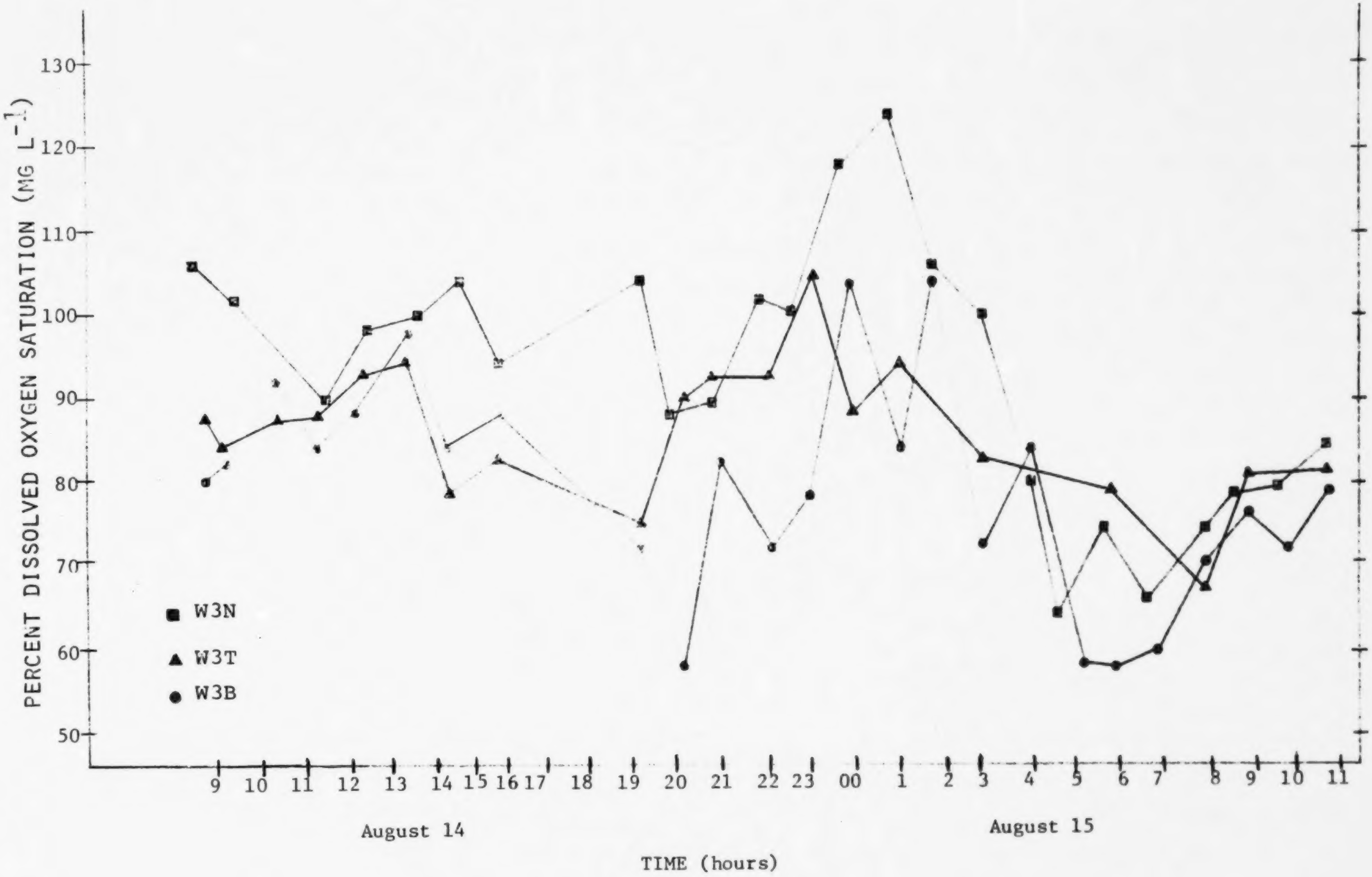


FIGURE 8. Percent dissolved oxygen saturation at transect W3, August 1979 Intensive Survey.

Results from the lateral and longitudinal analyses tend to indicate that the Ware River estuary is more homogeneous laterally than longitudinally. Lateral differences were found only along transect W3 and for only one parameter, dissolved oxygen. Longitudinal gradients, however, were discerned for salinity, total phosphorus and dissolved oxygen. Vertical differences were significant for dissolved oxygen, total phosphorus and suspended solids. It is interesting to note that in the Ware River, percent oxygen saturation was the only parameter that varied significantly between stations in all three directions (across the channel, along the channel and vertically through the water column). It appears that oxygen and salinity, relatively easy to measure parameters, may provide the best, first-cut indication of the existence of density stratification, as well as how this might affect water quality in the estuary.

2.2.2 1980 Intensive Survey

On July 9 and 10, 1980, a second intensive survey was conducted on the Ware River estuary. The survey was coordinated with the Chesapeake Baywide Nutrient Survey and also was a cooperative effort with Mr. Dale Phillips of the Virginia State Water Control Board and Mr. Wesley D. Jones, the Gloucester County Engineer. Phillips was interested in calibrating and evaluating a stream transport model of Foxmill Run from above the sewage treatment plant to the mouth of the Ware River estuary.

The 1980 Intensive Survey was conducted during a relatively dry summer. Less than 2 inches of rain fell during the 30 day period preceeding the survey. This was 2.3 inches below the monthly mean rainfall recorded for that time period for the past 13 years (National Weather Service, Bohannon, VA). Freshwater flow at the USGS gaging station at Beaverdam Swamp, however, averaged 7.6 cfs during the survey which is about normal, based on the discharge recorded at the gage for the past 30 years. The higher-than-anticipated flow was probably due to 0.3 inches of rain that fell in the watershed 2 days prior to the survey.

Weather conditions were somewhat similar to the first year's survey. Estuarine water temperatures ranged from 25 to 30 C. Skies were mostly clear on the 9th, air temperatures ranged from 72 to 86 F (22-30 C) and winds were out of the east, 3-11 mph. Near midnight, squall warnings were issued and winds of up to 23 mph out of the northwest were recorded fo several hours; only a trace of precipitation was measured. On the 10th, the skies were partly cloudy, air temperatures ranged from 74 to 88 F (23 -31 C) and winds were calm out of the southwest, 3-11 mph.

A total of 11 stations in the estuary, 6 freshwater stream sites and the Gloucester sewage treatment plant, the single point-source discharge into the estuary, were monitored around-the-clock for slightly over two tidal cycles (27 hours).

Temperature, salinity and dissolved oxygen were measured hourly while samples for nutrients, chlorophyll-a, pH, alkalinity, carbonaceous biochemical oxygen demand and suspended solids were collected every 3 hours. Additionally, the upstream stations (W4, W5, WFM1, FM2, FM3, WBS1, BS6, BS8) were sampled hourly for silica, total phosphorus, nitrite-nitrogen and nitrate-nitrogen. A set of ultimate biological oxygen demand measurements, plankton biomass determinations and identification of major phytoplankton groups were conducted as well.

Two tide gages and 5 current meters were deployed in the estuary to provide hydrographic information during the survey.

Longitudinal Differences

Mean oxygen concentrations (percent saturation) were highest toward the river mouth (W2T) and lowest in the upstream brackish regions. The point-source stream stations (FM2, FM3) had lower oxygen values than the stations in the tributary which had only nonpoint source inputs. The greatest variation in estuarine oxygen concentrations occurred in the brackish area. Values ranged from 9.52 mg/l (130.3% saturation) at WBS1 to 3.24 mg/l (38.9%) at FM2.

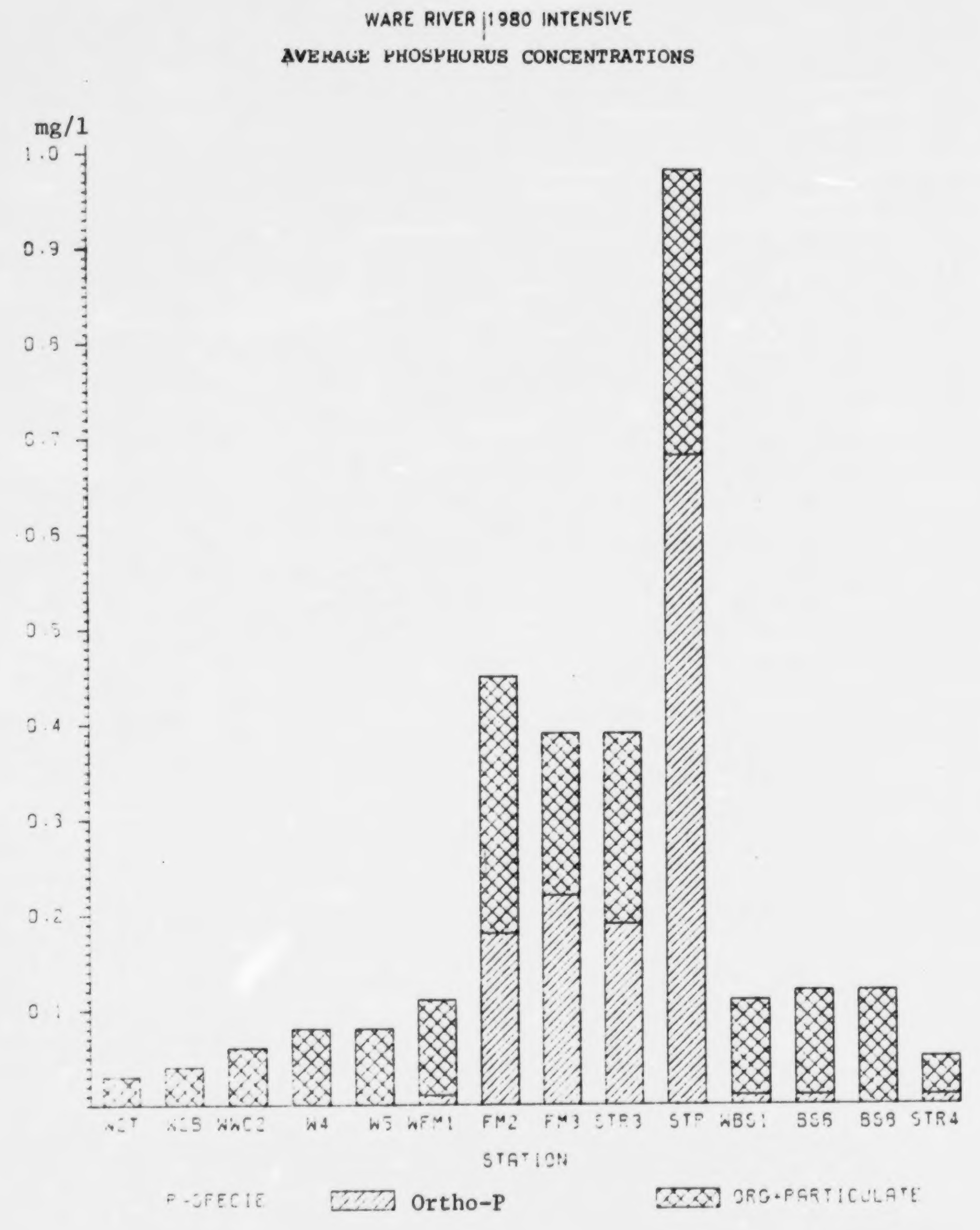
Average salinities at the mouth were 18.2 ppt. Station W5 averaged 17.1 ppt which is 2.5 ppt above the seasonal average and 4.3 ppt above the 1979 Intensive Survey averages recorded at that station. Salinities decreased rapidly with distance upstream, reflecting an even stronger longitudinal salinity gradient in the upper reaches of the estuary. For example, there was approximately at 0.7 ppt per km change in salinity concentration at low water slack between the mouth and the mid-reaches of the estuary. Near the landing (W5), a gradient of 2.2 ppt per km occurred. In the transition zone, salinity gradients were very large, on the order of 17 ppt per km.

Low suspended solids concentrations were found downstream (10 mg/l); particulate matter was greatest in the brackish regions just upstream from the landing (WFM1, 34.8 mg/l; WBS1, 32.9 mg/l).

Dissolved silica exhibited a longitudinal gradient, which would be expected from a somewhat conservative element. Concentrations ranged from 8 mg/l in the freshwater stream sites to 2.3 mg/l at the mouth of the estuary. Brackish regions contained an average of 4 mg/l of silicate.

Dissolved orthophosphorus was measurable only in Foxmill Run, presumably due to effluent from the sewage treatment plant. Concentrations were 6.8 mg/l at the point of discharge and decreased to 0.2 mg/l in the upper brackish areas. At WFM1, values were below detection limit, as was also the case throughout the estuary.

Total phosphorus was excessive at the sewage treatment plant outfall (9.8 mg/l) and appeared to decrease due primarily to dilution in Foxmill Run (see Figure 9). However, concentrations increased slightly at FM2. This may indicate an important area of physical interactions in Foxmill Run (a turbidity maximum) since suspended solids also increased and salinity concentrations average 0.5 ppt. Phosphorus concentrations were moderate in the brackish region and decreased longitudinally towards the mouth. It should be noted that most of the phosphorus measured was not in the orthophosphate form.



Note: STP values have been divided by 10

Figure 9. Phosphorus specie mean concentration, July 1980 Intensive Survey.

Figure 9 and 10 are helpful illustrating the overall contribution of nutrients to the estuary by the sewage treatment plant. The majority of the measurable nitrogen, or approximately 50-100%, appeared to be organic in nature during the survey. Nitrate-nitrogen was more abundant than nitrite-nitrogen and may indicate nitrification is occurring. Ammonia-nitrogen in Foxmill Run had high levels recorded during the survey, comprising approximately 40% of the measurable nitrogen. Highest ammonia nitrogen values were recorded at the sewage treatment plant outfall (4.2 mg/l); values downstream in Foxmill Run were also elevated (0.2 mg/l).

Low total nitrogen to total phosphorus ratios by atomic weight (TN:TP), or periods of nitrogen-limiting conditions, were observed during the survey (Figure 11). At the mouth and mid-reaches of the estuary, nitrogen-limiting conditions appeared to be the result of low inorganic-nitrogen levels. In the marsh region, inorganic nitrogen levels were high; nitrate-nitrogen comprised the greatest fraction of the inorganic nitrogen. Maximum values of both inorganic nitrogen and total phosphorus were recorded in Foxmill Run, which resulted in the lowest recorded TN:TP ratios in the estuary.

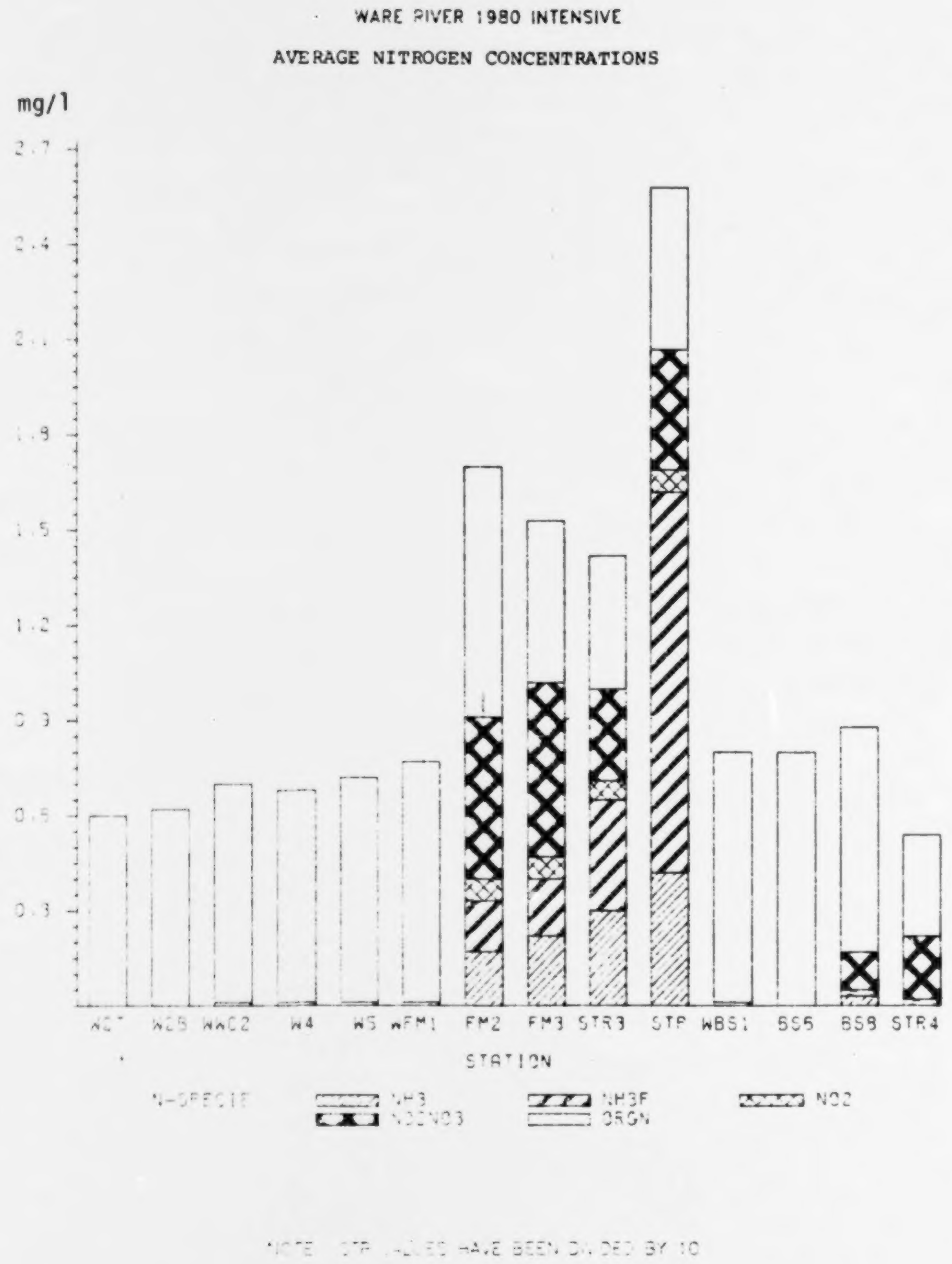
The TN:TP ratios both compare and contrast with the previous year's data. By contrast, the estuary was phosphorus-limited during the summer months of 1979. However, the nitrogen conditions present in Foxmill Run were consistant and even expected based on the low ratios recorded at the freshwater stream site (STR3) during the previous year. Presumably, such low TN:TP values are attributable to the wastewater discharge, since sewage is typically phosphorus rich.

Temporal and Diel Variations

Similar to the 1979 Intensive Survey, dissolved oxygen displayed a distinct diel periodicity. Oxygen concentrations were highest in mid-afternoon and lowest just prior to sunrise. The brackish region of Beaverdam Swamp had both the greatest oxygen supersaturation values (136%) as well as the greatest range in values recorded in the estuary (48.6% - 136%) over a 24 hour period.

By extending the 1980 Intensive Survey upstream into the tidal portions of the marsh, several interesting new patterns emerged. This time, highest chlorophyll-a values recorded in the estuary were at FM2 (37.1 ug/l), more than twice the values found in the estuary during the 1979 Intensive Survey.

At the mouth of the estuary, values averaged 10 ug/l and exhibited diurnal variations that appeared to correlate with sunlight rather than tidal stage. However, in the narrower upstream stretches of the marsh, diel patterns correlated more strongly with stage of tide than sunlight. A comparison of chlorophyll-a levels at FM3 and FM2 tends support the notion that phytoplankton populations increased during high tide (Figure



WARE RIVER 1980 INTENSIVE

AVERAGE NITROGEN CONCENTRATIONS

Figure 10. Nitrogen species mean concentrations, July 1980 Intensive Survey.

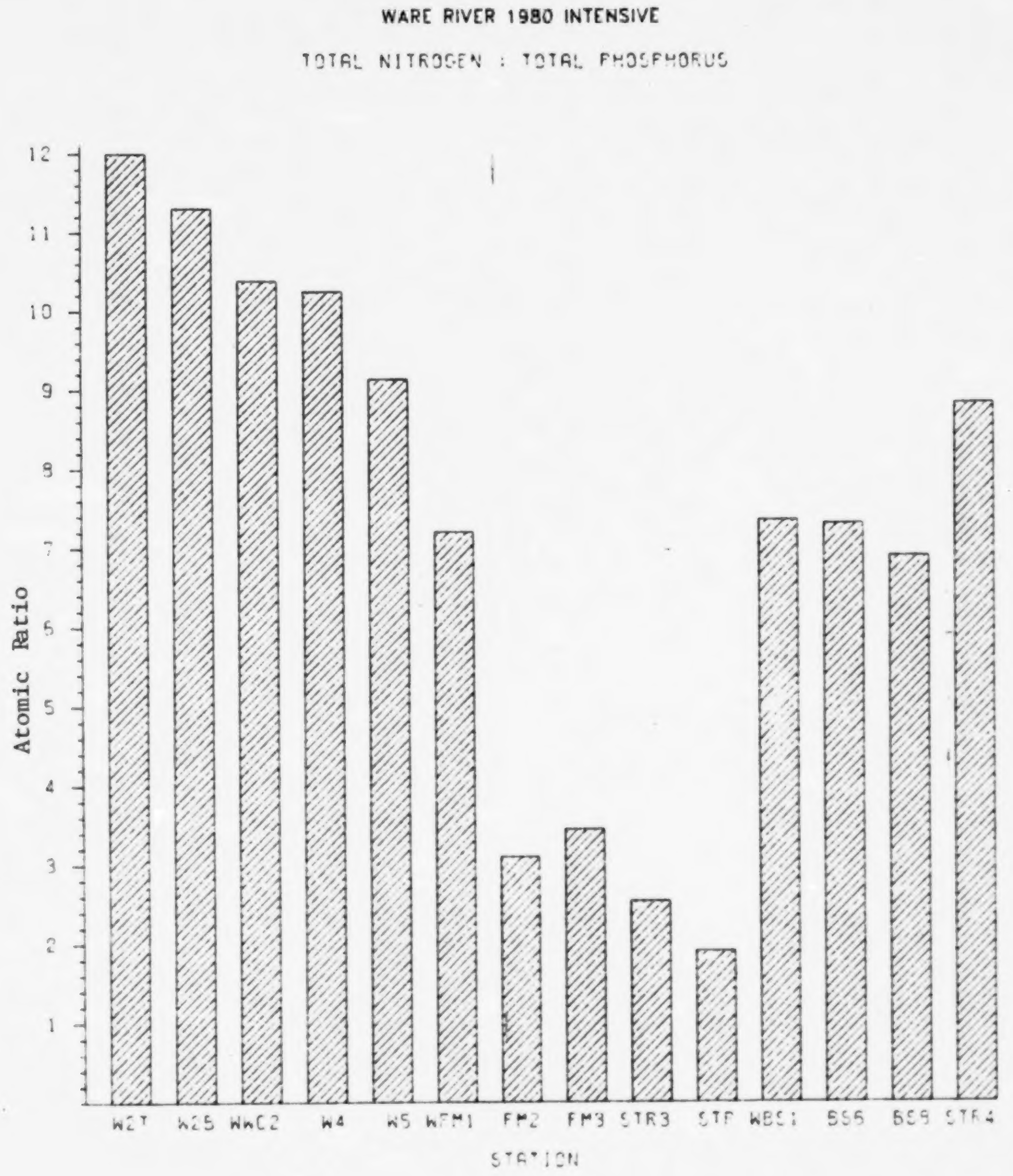


Figure 11. Average TN:TP ratios, July 1980 Intensive Survey.

12a), since neither salinity nor chlorophyll-a levels fluctuated at FM3 (at the head of tide region), but did so at FM2. In Beaverdam Swamp, conversely, elevated chlorophyll-a concentrations occurred during LWS, implying nonpoint source nutrient inputs from the marsh may be an important factor (Figure 12b).

Salinity concentrations were similar at STR3, STR4, and FM3, or roughly 0.2 ppt. Chlorophyll-a values were consistantly low, and homogeneous there, or less than 2 ug/l. At FM2, salinity gradients greater than 0.5 ppt occurred during HWS only. During these periods, significantly higher measurements of a chlorophyll-a were observed. Such increases in primary productivity tend to support the idea of a turbidity maximum at the freshwater/saltwater interface.

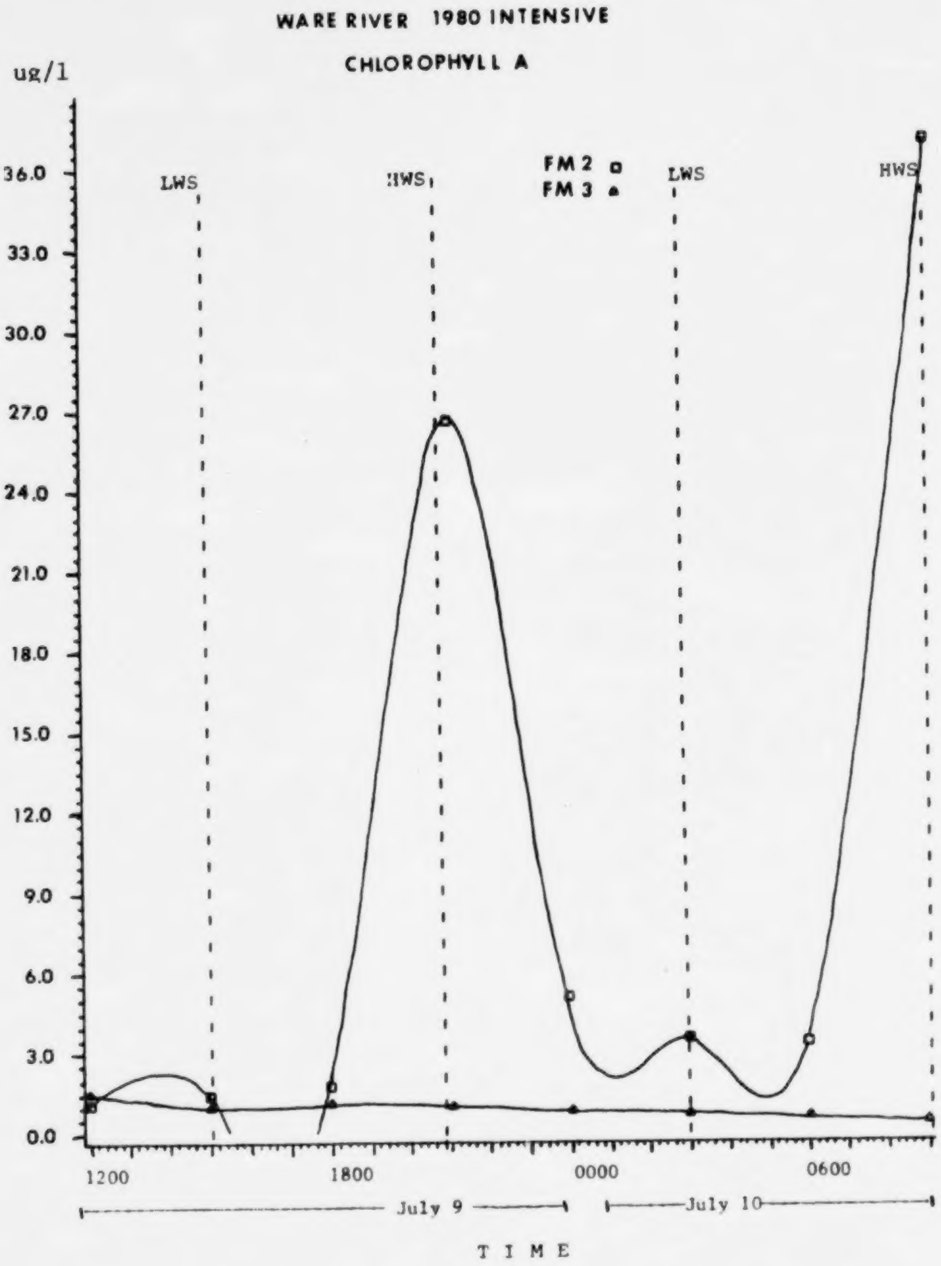


Figure 12a. Chlorophyll-a concentrations at FM2 and FM3, July 1980 Intensive Survey.

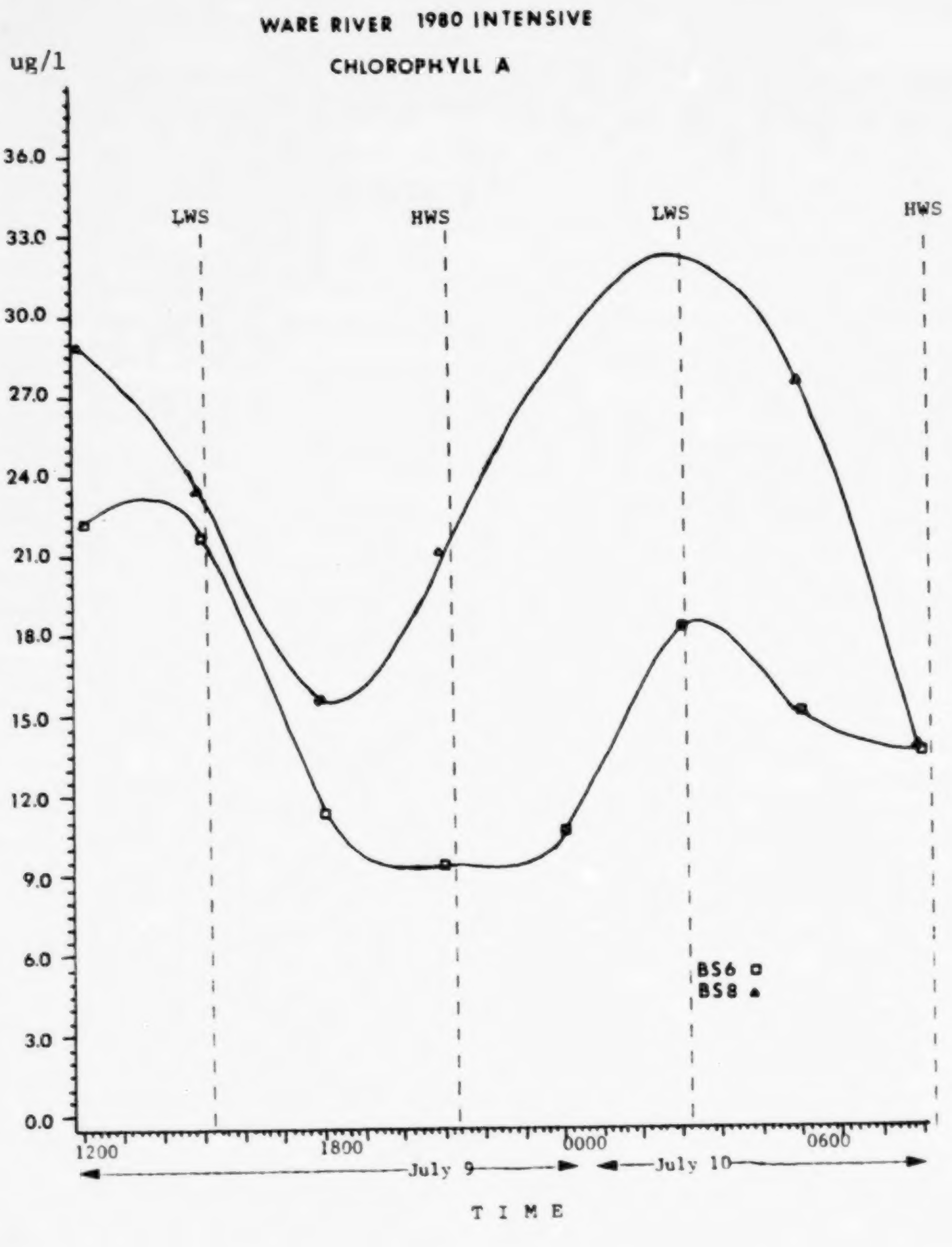


Figure 12b. Chlorophyll-a concentrations at BS6 and BS8, July 1980 Intensive Survey.

2.2.3 1981 INTENSIVE SURVEY -- March 25-26, 1981

One of the most dramatic annual phenomena observed in the Ware River estuary was the chlorophyll-a maximum that occurred each spring in 1979-1980. After collecting two complete data sets of diel fluctuations during consecutive summers (August 1979 and July 1980 Intensives), a spring intensive survey was planned for 1981.

The purpose of sampling in the spring was to capture the diel nutrient dynamics surrounding the chlorophyll-a maximum. The survey, conducted March 25-26, was designed to complement the ongoing Spring Survey of 1981 (see Section 2.4). Thirteen stations in the estuary, 7 freshwater stream sites and the Gloucester sewage treatment plant were monitored round-the-clock for 2 tidal cycles. Two of the estuarine stations (Pig Hill and Goshen) were sampled using automatic samplers.

In the estuary, grab samples were collected every three hours; the automatic samplers were set for hourly sampling. Temperature, pH, alkalinity, salinity, dissolved oxygen, chlorophyll-a, silicates, suspended solids, 5-day carbonaceous biochemical oxygen demand and nutrient samples were collected.

Water temperatures during the survey ranged from 6.5 to 10.5 C. Weather conditions were "seasonable" during the survey. Ambient temperatures ranged from 29 to 53 F (-1 to 11 C). On March 25th, winds were moderate and out of the north (5 - 16 mph), but shifted to a southerly flow by the next day (5 - 21 mph). No precipitation was recorded over the 24 hour period; previous rain had fallen on March 23 (0.39 in).

Longitudinal Differences

Average salinities at the mouth (W1) were 23.3 ppt; nine km upstream, at Warehouse Landing (W5), values declined slightly, to 22.6 ppt (Figure 13a), which was 5.5 ppt greater than during the previous intensive, and emphasizes the paucity of spring runoff. As in the 1980 survey, a strong longitudinal salinity gradient was present in the upper reaches of the estuary: at LWS salinity varied 20 ppt between WFM1 and FM2 reflecting a longitudinal gradient of 6.3 ppt per km. Similarly, in Beaverdam Swamp, salinity changed 4 ppt per km between WBS1 and BS8. Downstream gradients were indiscernable; at LWS there was 0 ppt change in the first 4 kilometers.

Mean dissolved oxygen (percent saturation) values were higher in the mouth of the estuary and in the freshwater streams, and lowest in the brackish reaches. Supersaturated conditions

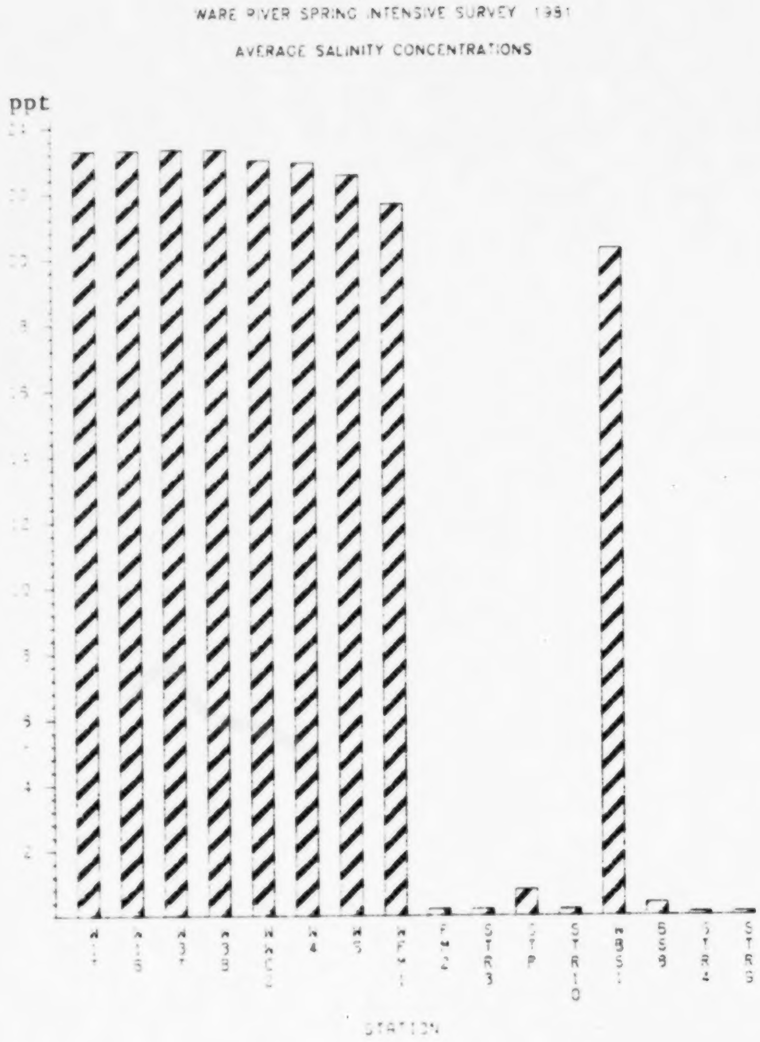


Figure 13a. Average salinity concentations, 1981 Intensive Survey.

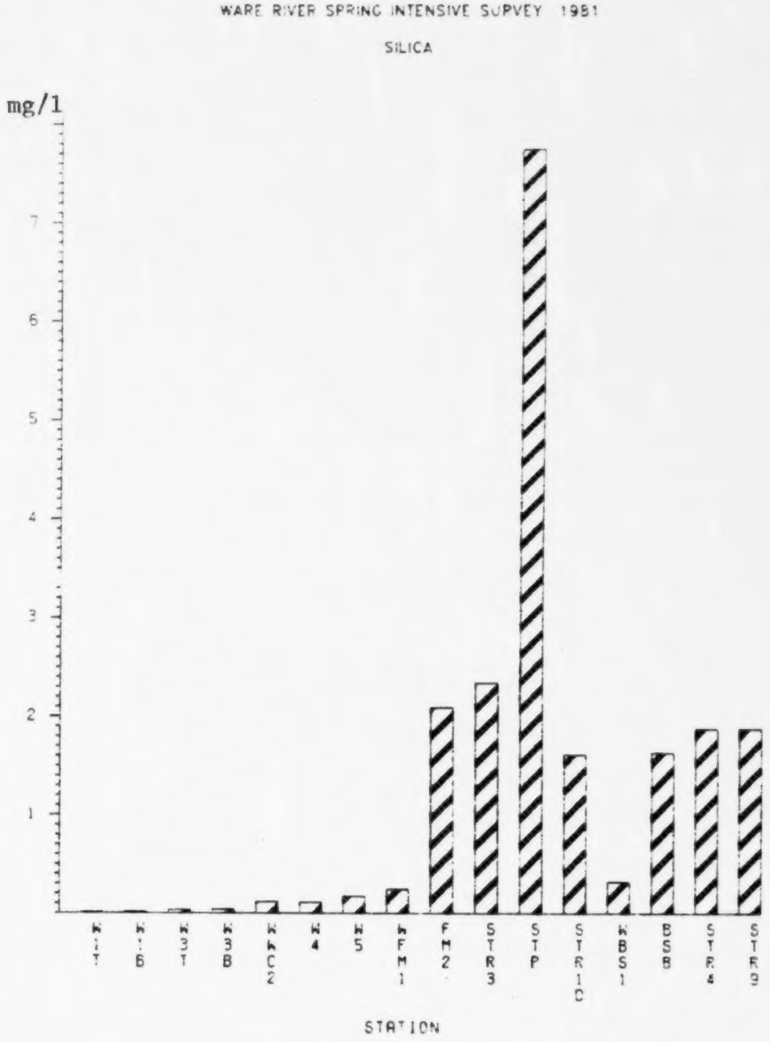


Figure 13b. Average dissolved silica concentrations, 1981 Intensive Survey.

existed at all stations downstream of Warehouse Landing. Highest values as well as the greatest range were present at W1B, where maximum chlorophyll-a values were also found. The point-source tributary (Fox Mill Run) contained lowest mean values, but due to the cool temperatures, saturation did not fall below 70%.

Silicates showed a strong longitudinal gradient during the spring survey. A significant decrease in concentration between stations WBS1 and BS8, and WFM1 and FM2 was found, which paralleled the limit of freshwater intrusion (Figure 13b). Levels at the STP were similar to 1980 survey values (7.6 mg/l). However average values in the main stem of the estuary were less than 0.5 mg/l, almost 2 mg/l less than what was present the preceeding summer, which would be expected during reduced baseflow conditions.

Aside from the STP, chlorophyll-a values were highest at the mouth of the estuary (Figure 14). In general, mean values decreased with rivermile, tending to confirm the subsurface transport of phytoplankton as found in 1979. Concentrations were extremely low, however; maximum values in the estuary (W1B) were 2.5 ug/l.

As expected STR3 had the highest BOD values (5.7 mg/l). One kilometer downstream, levels dropped rapidly and the remainder of the stations sampled were not significantly different, averaging less than 2.0 mg/l (Figure 15).

Suspended solids were highest in the brackish region of the marsh and were lowest in the surface waters at the mouth (W1T=1.8 mg/l). Values also decreased upstream of WBS1 and WFM1 (Figure 16).

Filterable orthophosphates were measurable downstream of the point-source in Foxmill Run only (Figure 17). Concentrations returned to baseline (as observed upstream of the STP at STR10) at WFM1 of 0.01 mg/l. Concentrations were uniformly undetectable in the main stem of the estuary. The NPS freshwater tributary (STR4) contained little orthophosphates whereas orthophosphorus predominated in the point-source tributary.

Total phosphorus was high at the sewage treatment plant (6.5 mg/l) and decreased with distance downstream (Figure 17). At station WFM1, background levels (as measured at STR 10) had returned to 0.03 mg/l. Concentrations were above detection limits (0.01 mg/l) at all stations, however, no longitudinal trend was observed.

Extremely high concentrations of total Kjeldahl nitrogen were measured at the STP ($\bar{X}$=30.3 mg/l). Slightly less than half of the total Kjeldahl nitrogen was in the dissolved form (13.7 mg/l). At all other stations, dissolved total Kjeldahl nitrogen represented at least 75% of the measurable fraction (Figure 18). Nitrite-nitrogen was not measurable in the estuary except at STP and FM2. Nitrate-nitrogen was slightly more prevalent but was

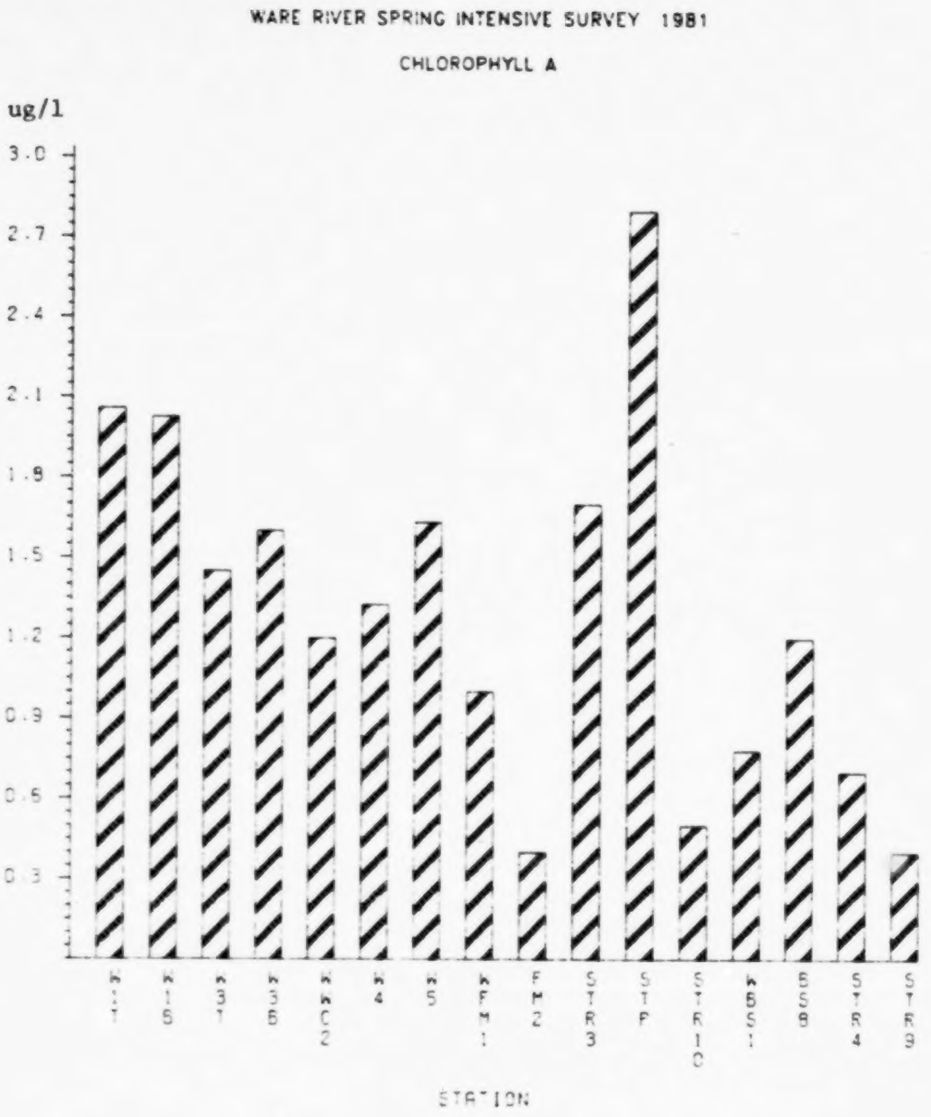


Figure 14. Average Chlorophyll-a concentrations, 1981 Intensive Survey.

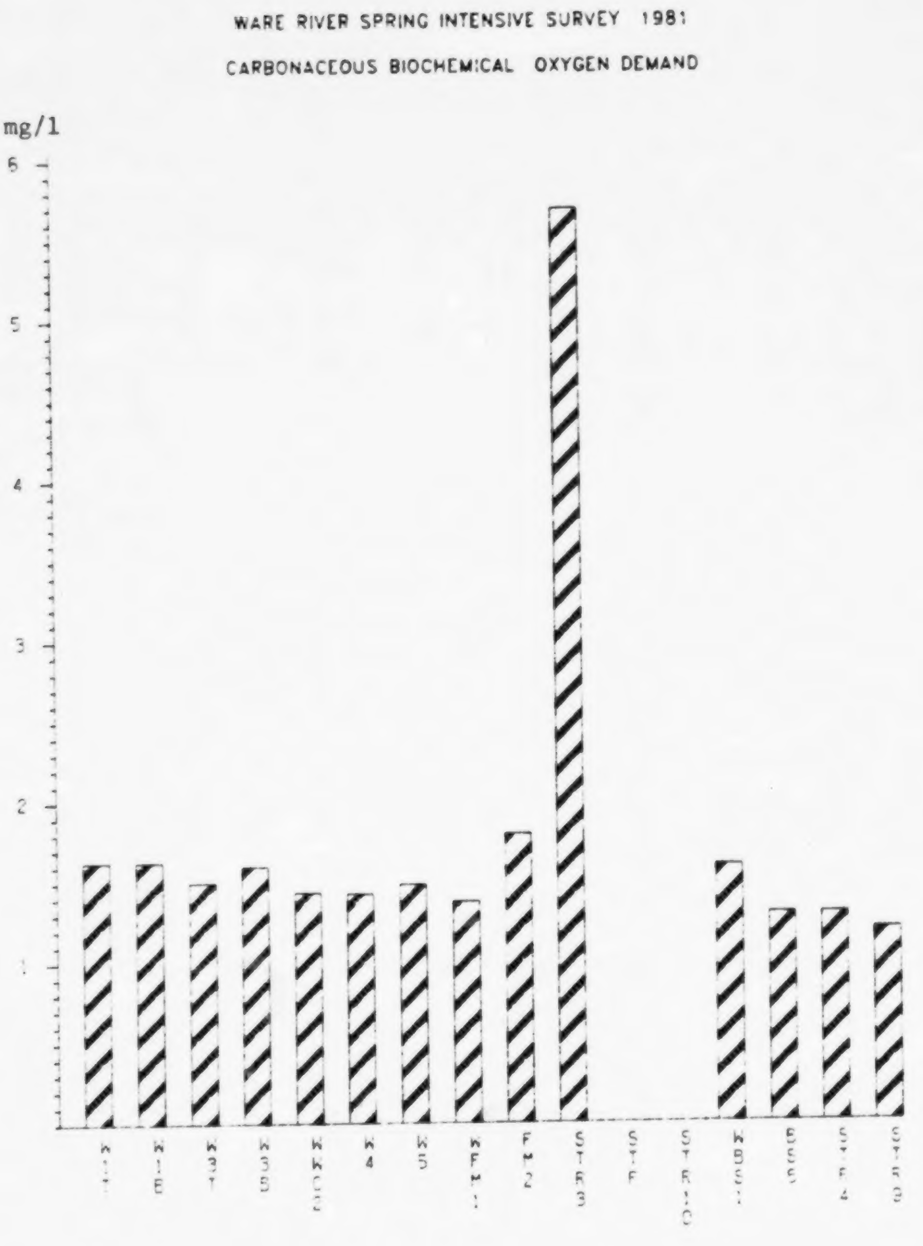


Figure 15. Average carbonaceous biochemical oxygen demand, 1981 Intensive Survey.

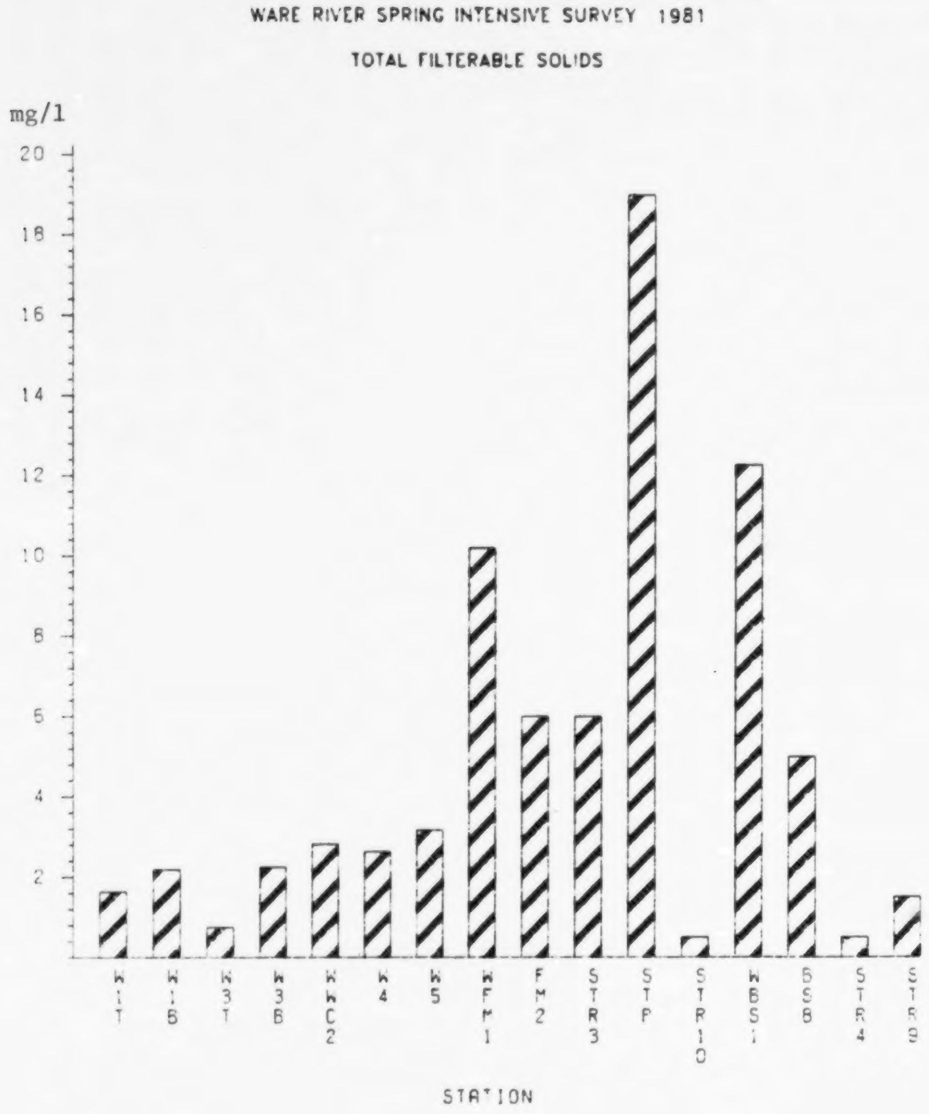


Figure 16. Average total filterable solids, 1981 Intensive Survey.

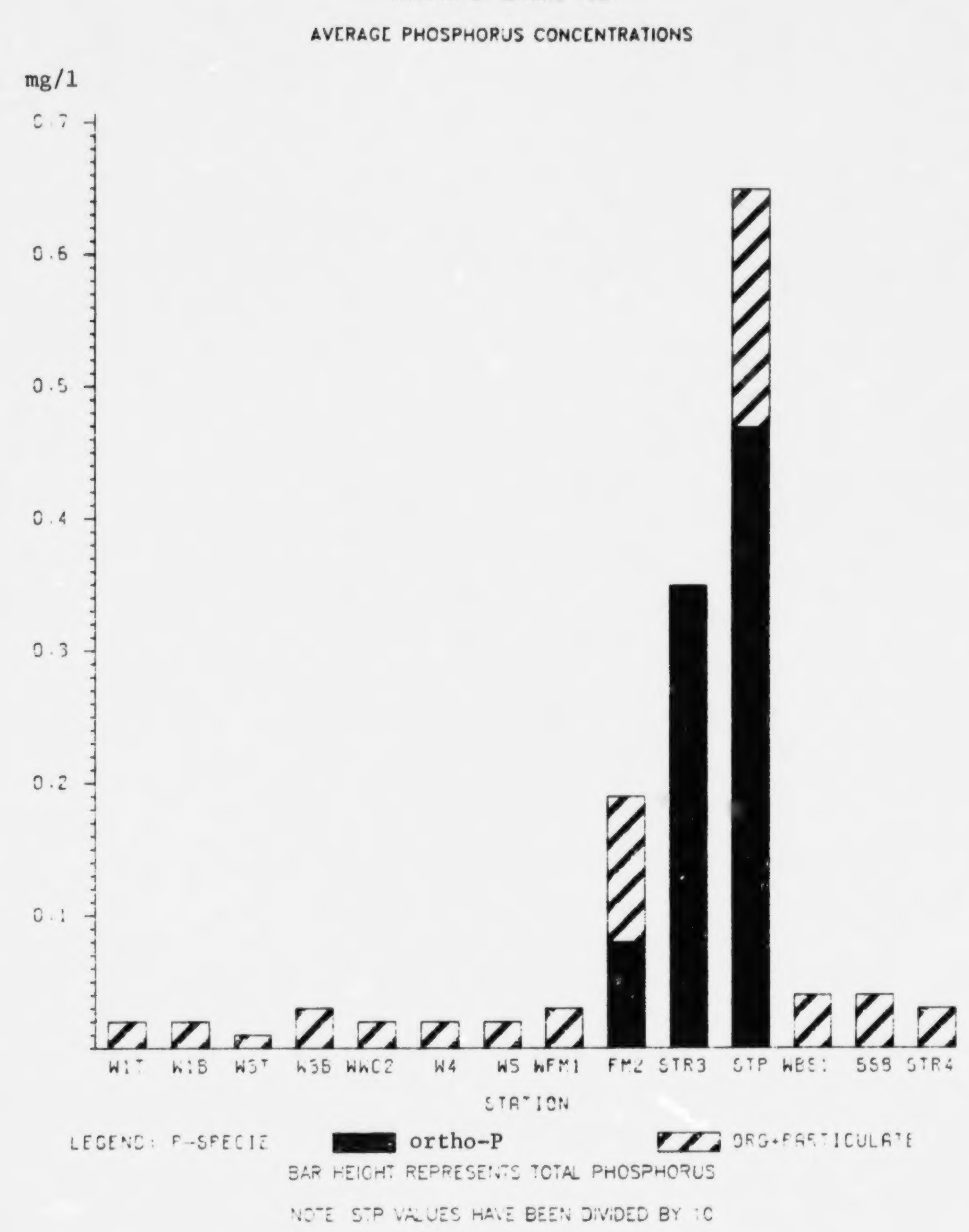
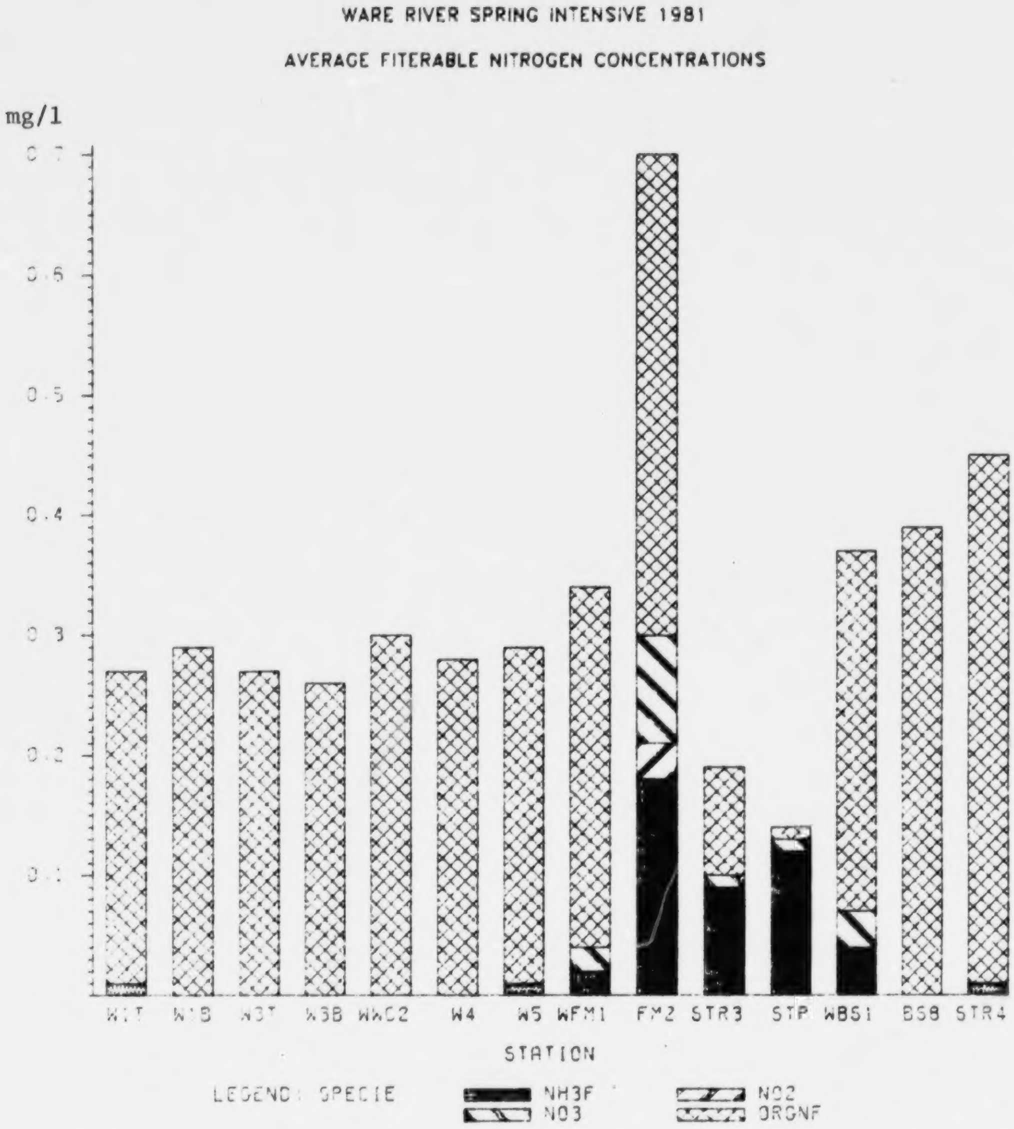


Figure 17. Phosphorus species mean concentrations, 1981 Intensive Survey.



NOTE STP VALUES HAVE BEEN DIVIDED BY 100

STR3 VALUES HAVE BEEN DIVIDED BY 10

Figure 18. Nitrogen species mean concentrations, 1981 Intensive Survey.

measurable only upstream of station W5. Ammonia-nitrogen values similarly exhibited a longitudinal gradient. Values were below detection limit downstream of W5; values were high at the STP (12 mg/l) and returned to baseline by WFM1.

Interestingly enough, WBS1 contained higher mean values for inorganic nitrogen than WFM1, the point source tributary. Most of the contribution was in the ammonia-nitrogen form, and indicates the importance of nonpoint source contributions from the marsh in this region.

Nitrogen limiting conditions were present at the STP and in Fox Mill Run. All other stations, including freshwater tributaries, had high ratio values (Figure 19a) indicating phosphorus limiting conditions. The same pattern was observed in 1979, which would be expected since Chesapeake Bay is generally considered to be a phosphorus limited estuary, and sewage is typically phosphorus rich.

Values for dissolved inorganic nitrogen:orthophosphorus were calcuable in Fox Mill Run and WBS1 only (Figure 19b). At the other stations, orthophosphorus was too low to use in calculations.

There was no longitudinal gradient for total organic carbon concentrations in the estuary (Figure 20). Stations were not significantly different from each other and averaged 4.0 mg/l. Values at the sewage treatment plant were high (128.7 mg/l).

Temporal and Diel Variations

Similar to the two preceeding intensive surveys, dissolved oxygen showed a distinct diel periodicity. Times of maximum oxygen concentrations occurred in the late afternoon (1830 hours); lowest values occurred just prior to sunrise (0430 hours).

Silicates exhibited a tidally related pattern in the brackish area: high values were associated with LWS. Temporal variations in several other nutrient concentrations were also most evident in the brackish region. Maximum values for total Kjeldahl nitrogen, ammonia-nitrogen, total organic carbon and total phosphorus occurred at times of low water slack; minimum values were present at high water slack. Station W1T was the only exception: higher total Kjeldahl nitrogen values were present at HWS.

Chlorophyll-a and biochemical oxygen demand showed no temporal or diel variation in the estuary. This was probably due to the fact that overall values were quite low at this time of year.

Suspended solids were similarly low during the spring intensive, especially downstream. Stations in the brackish area (WBS1, W5, Pig Hill and Goshen), however, demonstrated a tidal

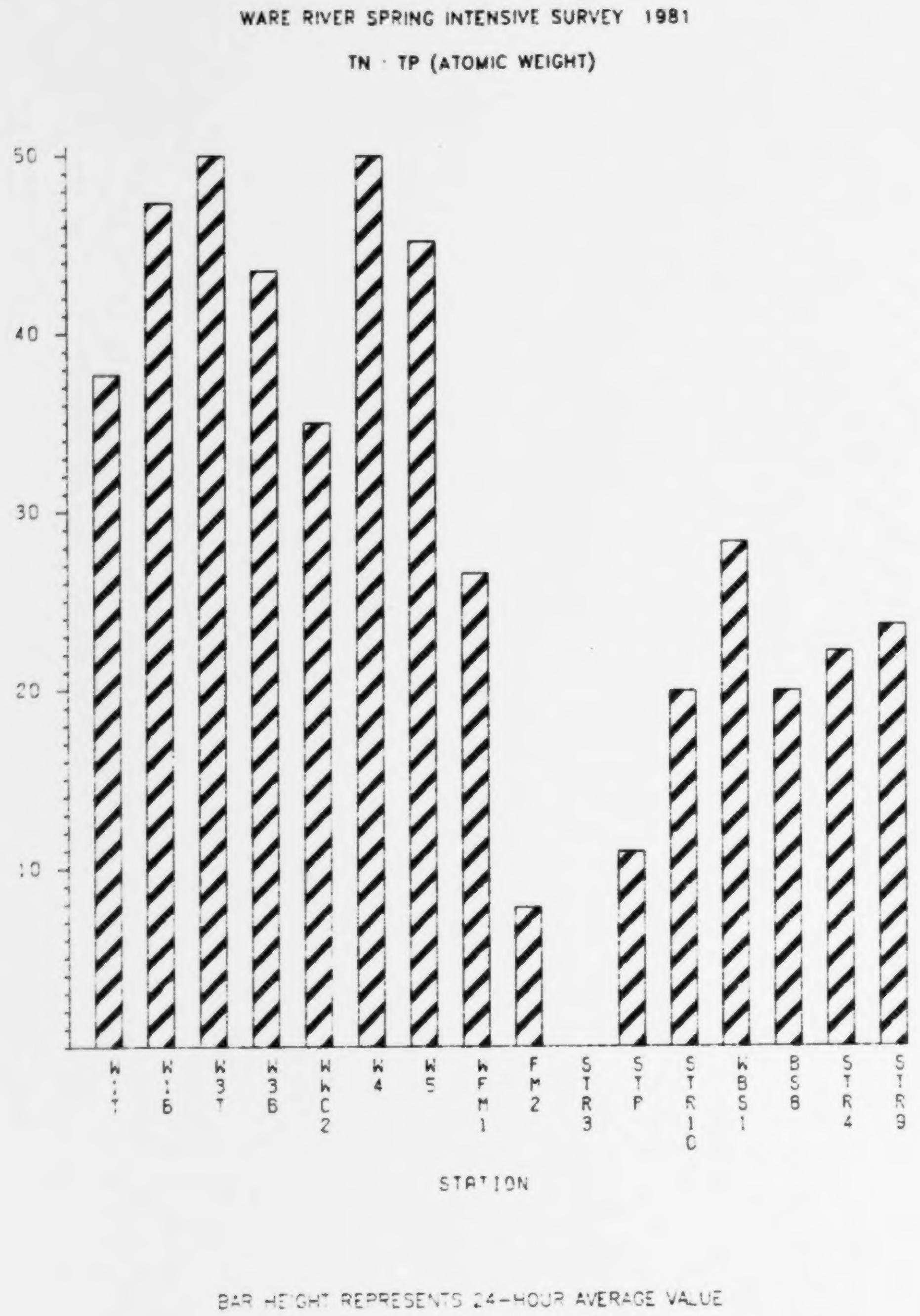


Figure 19a. Average TN:TP ratios, 1981 Intensive Survey.

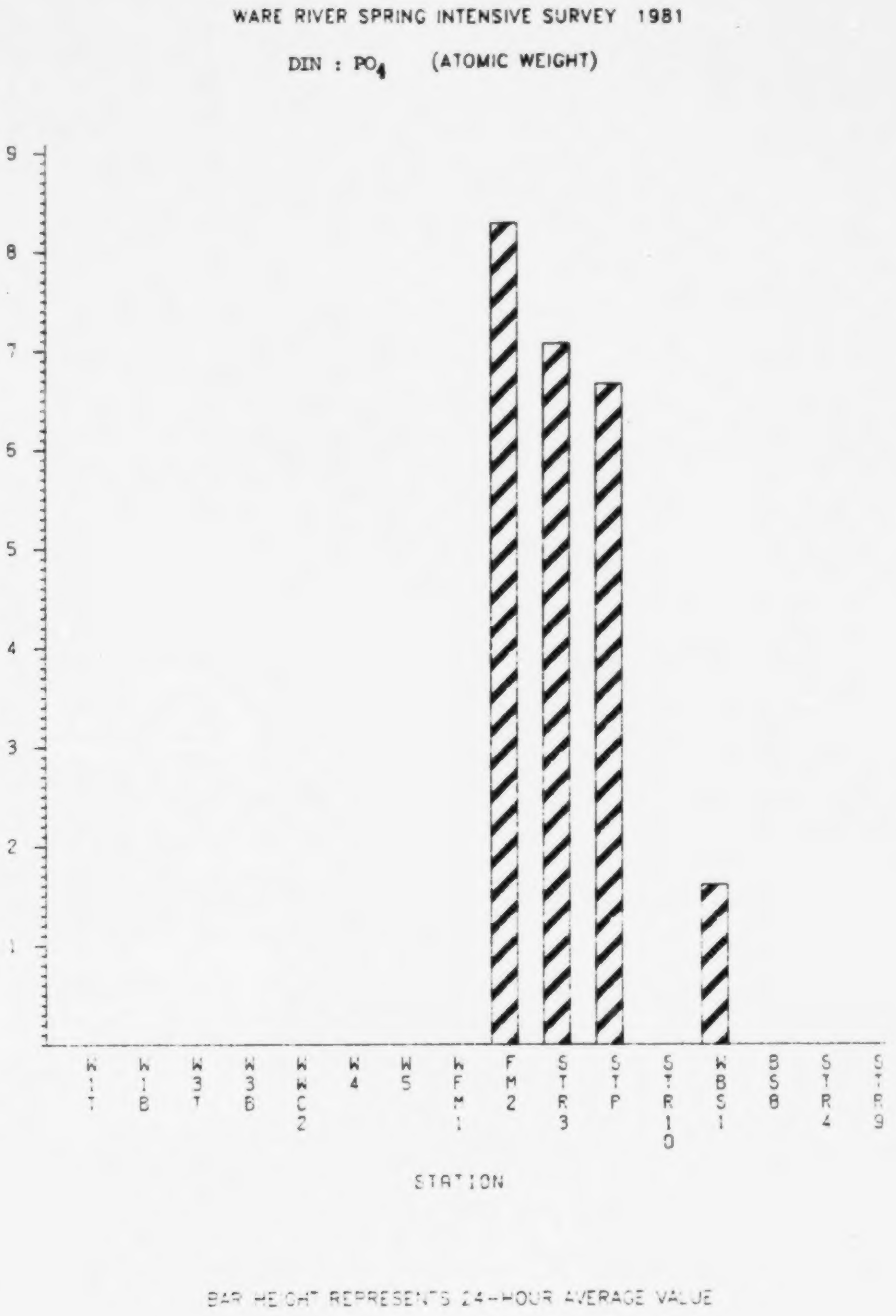
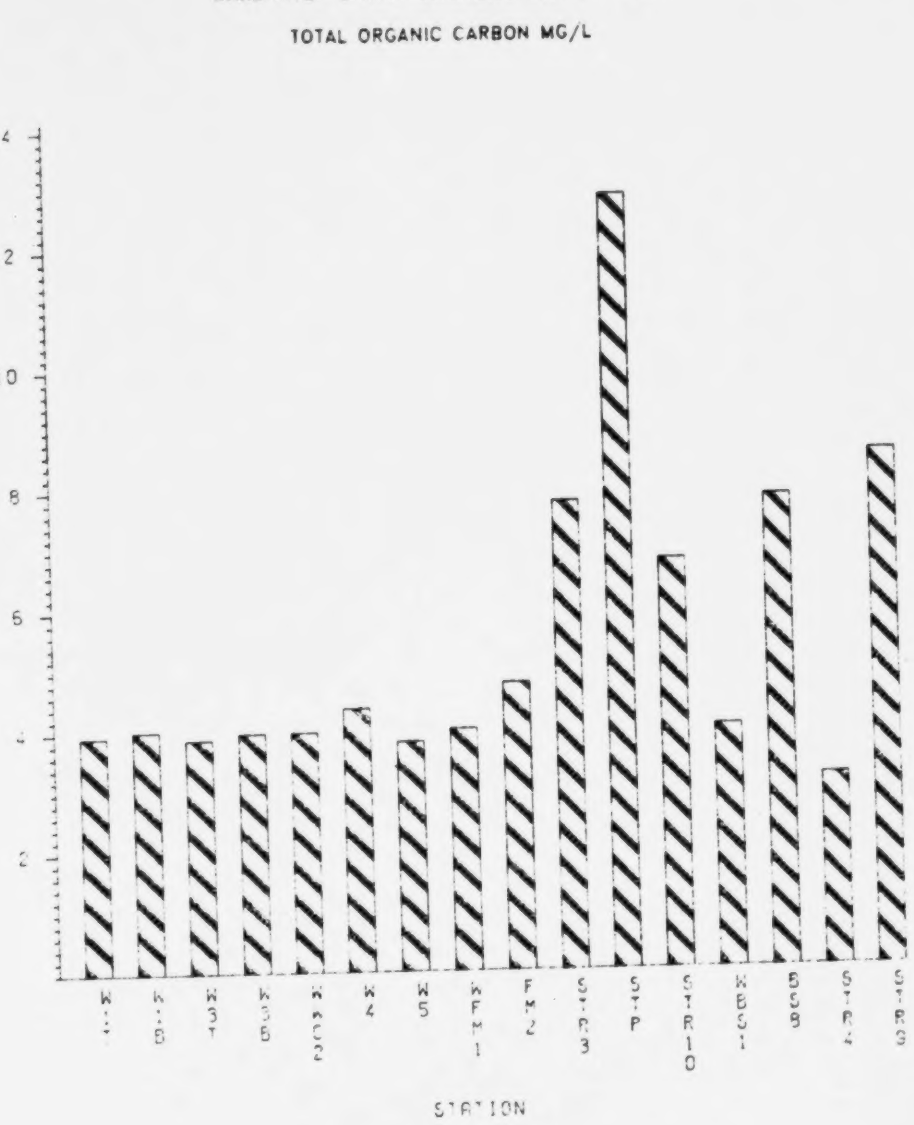


Figure 19b. Average $DIN:PO_4$ ratios, 1981 Intensive Survey.



BAR HEIGHT REPRESENTS 24-HOUR AVERAGE VALUE

STP VALUES HAVE BEEN DIVIDED BY 100

Figure 20. Average TOC concentrations, 1981 Intensive Survey.

relationship: highest concentrations occured during LWS, low values were present at HWS.

2.3 TREND ANALYSES: April 1979 - July 1981

In order to determine the natural variations in nutrients and related elements in a system that is not overenriched, a water quality sampling program was initiated on the Ware River estuary in April 1979. Semi-monthly highwater slack surveys were conducted during the first year; monthly slack surveys with more upstream (tidal marsh) stations were implemented in the second year. (See Appendix A for a list of sampling dates and times and other information.) Seasonal means, standard deviation and variance were calculated for each station. Seasons were defined as:

Season	Month	Water Temp.
Spring	April, May, June	10 - 20 C
Summer	July, August, September	20 - 30 C
Fall	October, November, December	25 - 10 C
Winter	January, February, March	< 10 C

Results were plotted against time to concatenate seasonal trends. Salient findings from the seasonal slackwater data follows. Note: no appreciable longitudinal temperature variation was found between stations in the main stem of the estuary during the 27 month study.

Chlorophyll-a

Chlorophyll-a exhibited a distinct spring peak in 1979 and 1980 in the main stem of the estuary (Figure 21), coincident with rapid temperature rises in the estuary (Figure 22). Chlorophyll-a values of 25-35 ug/l were observed which is several times the annual average of 9.5 ug/l. Greatest concentrations at this time were found in the bottom waters at the mouth and this may reflect an annual long-range subsurface transport phenomenon of plankton as observed in Chesapeake Bay for *Prorocentrum mariae-leboriae* (Tyler and Seliger, 1978). The apparent spring subsurface chlorophyll maxima in the Ware River was followed by a surface bloom; chlorophyll-a values at the mouth decreased thereafter with depth until fall. In addition to the spring blooms, a secondary summer pulse (12-15 ug/l) was observed in the brackish waters, illustrating the patchy and ephemeral nature of plankton populations.

Phytoplankton enumerations into major groups were made seasonally at several stations throughout the estuary to augment chlorophyll-a data. Cell counts showed diatoms to be the dominant organism in the downstream stations throughout the year.

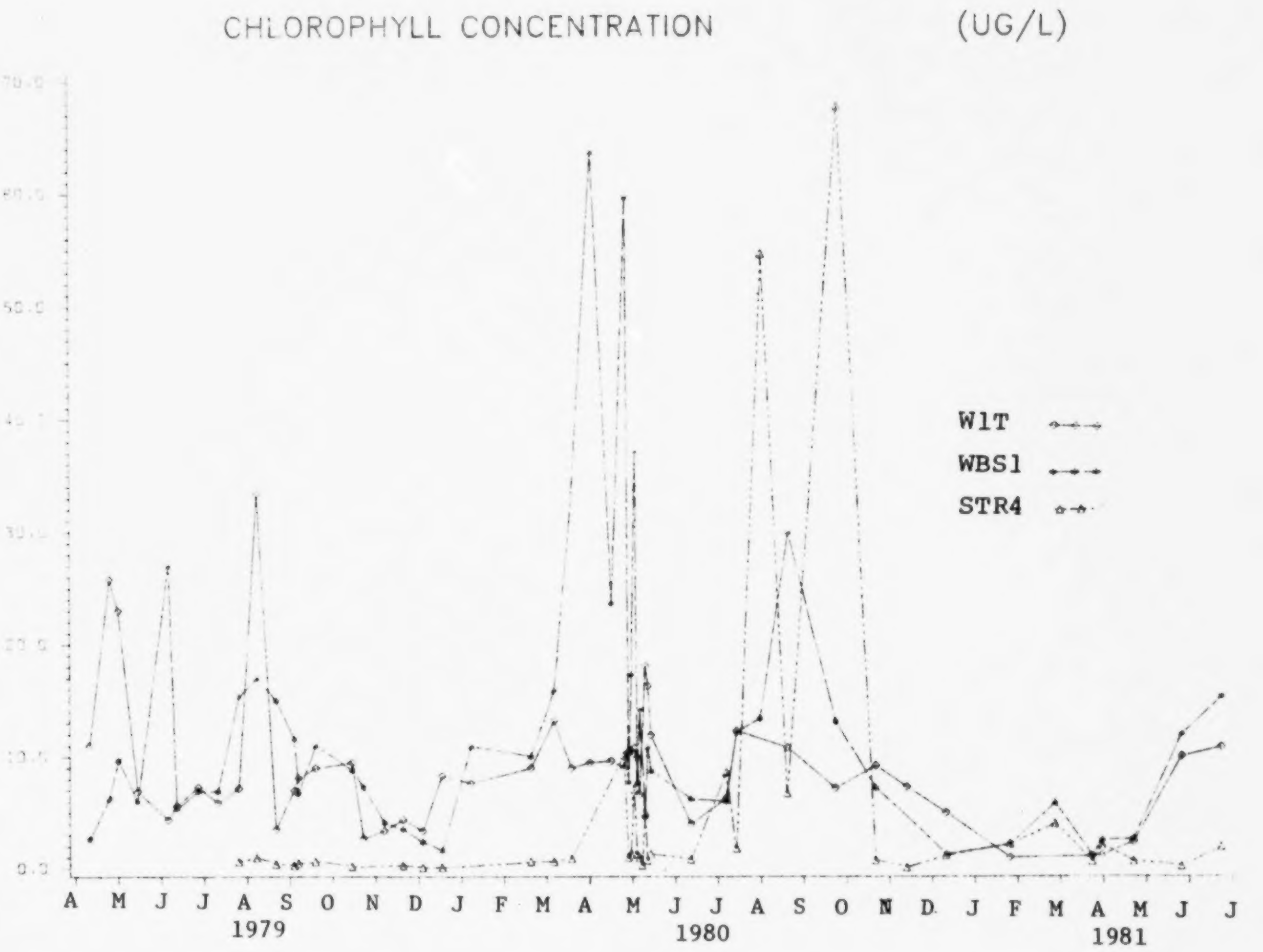


Figure 21. Time-series plot of chlorophyll-a concentrations, Stations W1T, WBS1, STR4.

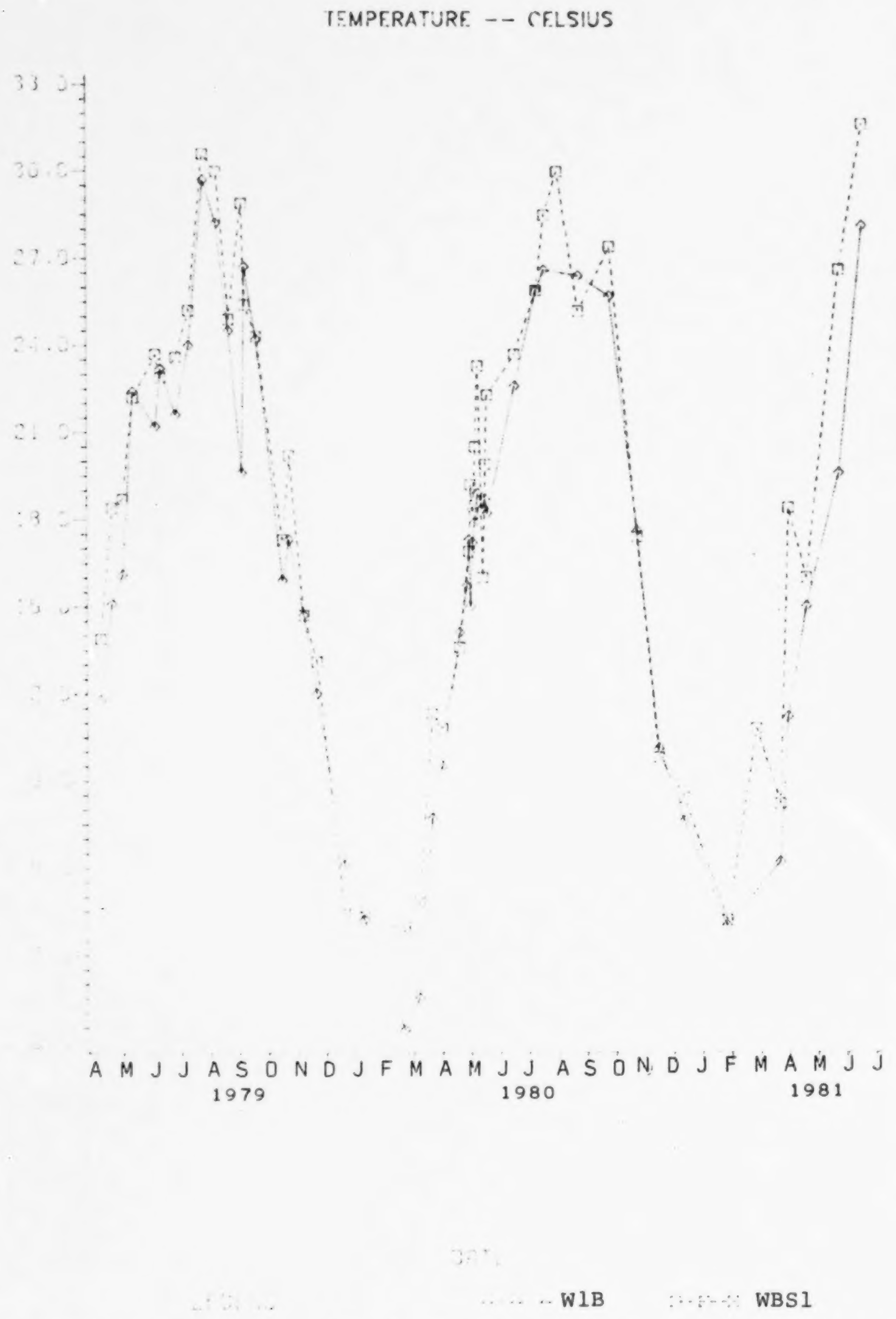


Figure 22. Time series plot of temperature, Stations W1B and WBS1.

The classical spring chlorophyll-a peak in 1980 contained mostly diatoms, primarily Rhizosolenia and Nitzchia. Diatoms continued to dominate throughout the year, however cell counts were low in summer. The downstream spring peak was followed by an upstream period of dinoflagellate dominance. Times of dinoflagellate blooms were associated with high chlorophyll-a values and low nitrite-nitrate nitrogen concentrations, since nitrite-nitrogen usually is an important source of nitrogen and is assimilated rapidly by the bloom organisms. This pattern has been observed previously in the Rhode River (Seliger, 1972). Green flagellates increased in number during the summer months and by fall diatoms were present in the brackish region. In the middle reaches of the estuary, phytoplankton populations appeared to reflect an intermediate assemblage; diatoms predominated throughout the year except during the summer, when green flagellates were most numerous.

Biochemical Oxygen Demand

Nitrogen-inhibited carbonaceous biochemical oxygen demand measures the amount of oxygen required by microrganisms to decompose aerobically the carbonaceous fraction of organic matter present in a water sample. Total biochemical oxygen demand is a measure of the oxygen needed to decompose carbonaceous as well as nitrogenous fractions of organic matter. As expected, total BOD exerted a slightly higher demand than carbonaceous BOD, although the two were highly correlated (r=.90, n=676).

Both parameters showed much the same pattern as chlorophyll-a throughout the study period and, in fact, correlated slightly (r=.72, n=624 for BOD5; r=.69, n=888 for BOD5I). Highest BOD values occurred in the freshwater streams and tidal tributaries (STR6, STR3, FM2). Highest estuarine oxygen demand was found during the spring in the bottom waters near the mouth (W1B). Peaks were observed throughout the estuary in the summer and fall, as well (Figure 23). Measurements above 5 mg/l are considered by some to be indicative of slightly polluted waters (Ott, 1978); this occurred 37 times in the Ware River out of 931 stations sampled. Values never rose above 8.0 mg/l.

Nutrients

Nutrient concentrations are generally low in the Ware River estuary especially when compared to the freshwater tributaries or to larger, more urbanized systems. At no season or station were anoxic conditions encountered in the estuary. However, there was a distinct longitudinal gradient present in the estuary: percent saturation of dissolved oxygen was significantly higher at the mouth than in the upstream reaches. The study average showed 90% oxygen saturation present at W1B; WBS1 had only 70%. Lowest and highest values were found during the summer months (Figure 24), due to large diurnal fluctuations caused by photosynthesis and respiration.

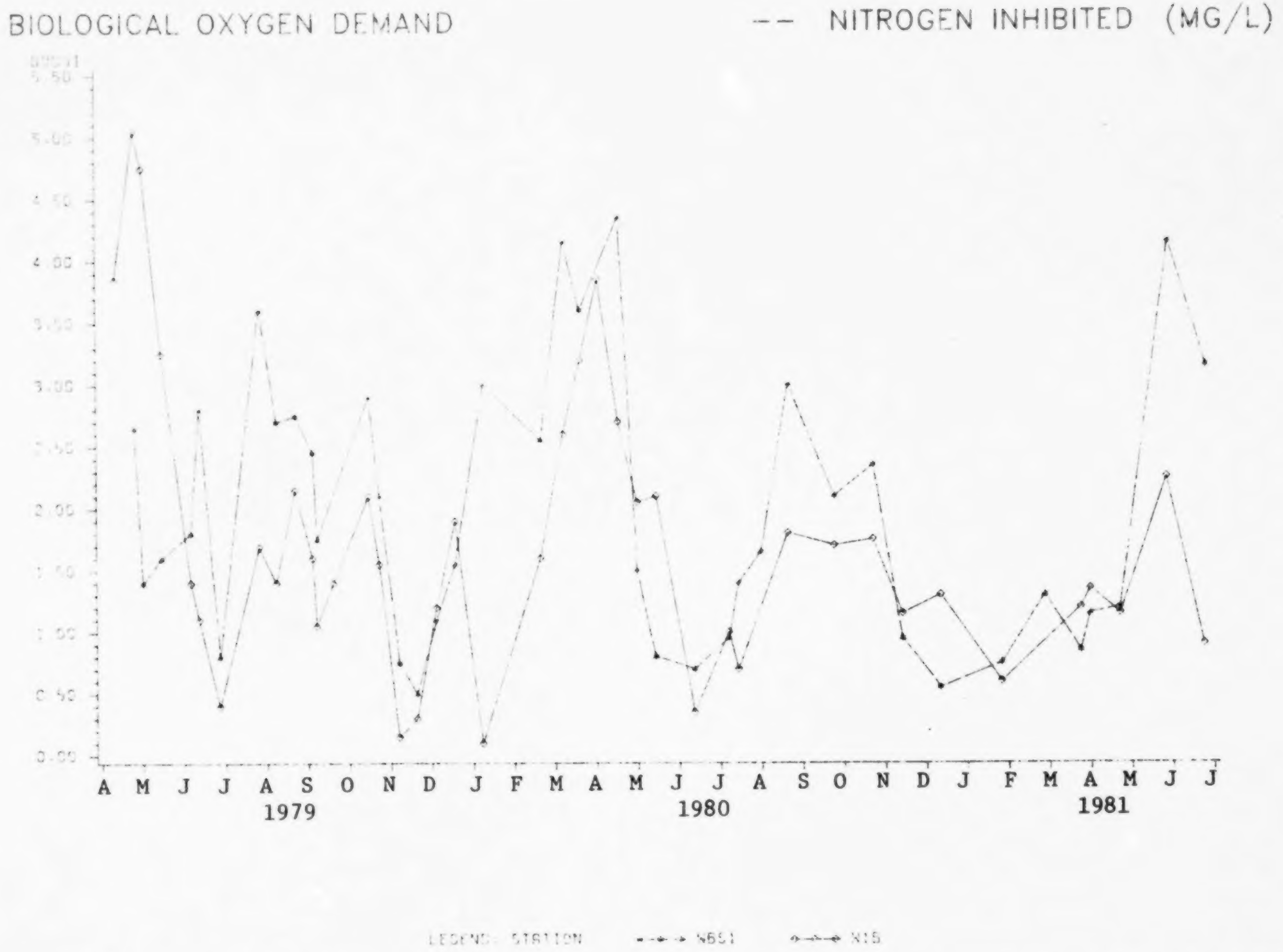


Figure 23. Time-series plot of carbonaceous biochemical oxygen demand, Stations W1B and WBS1.

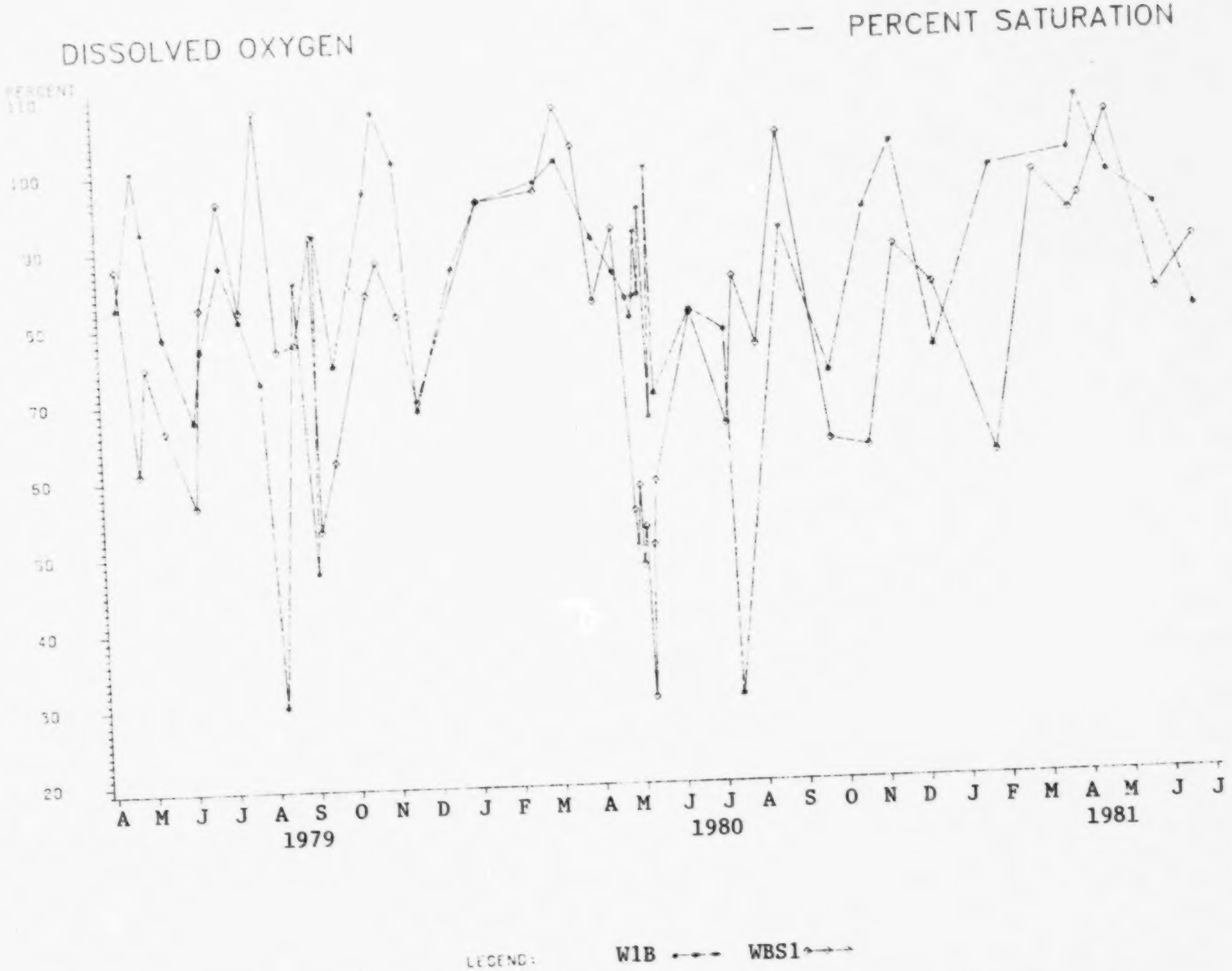


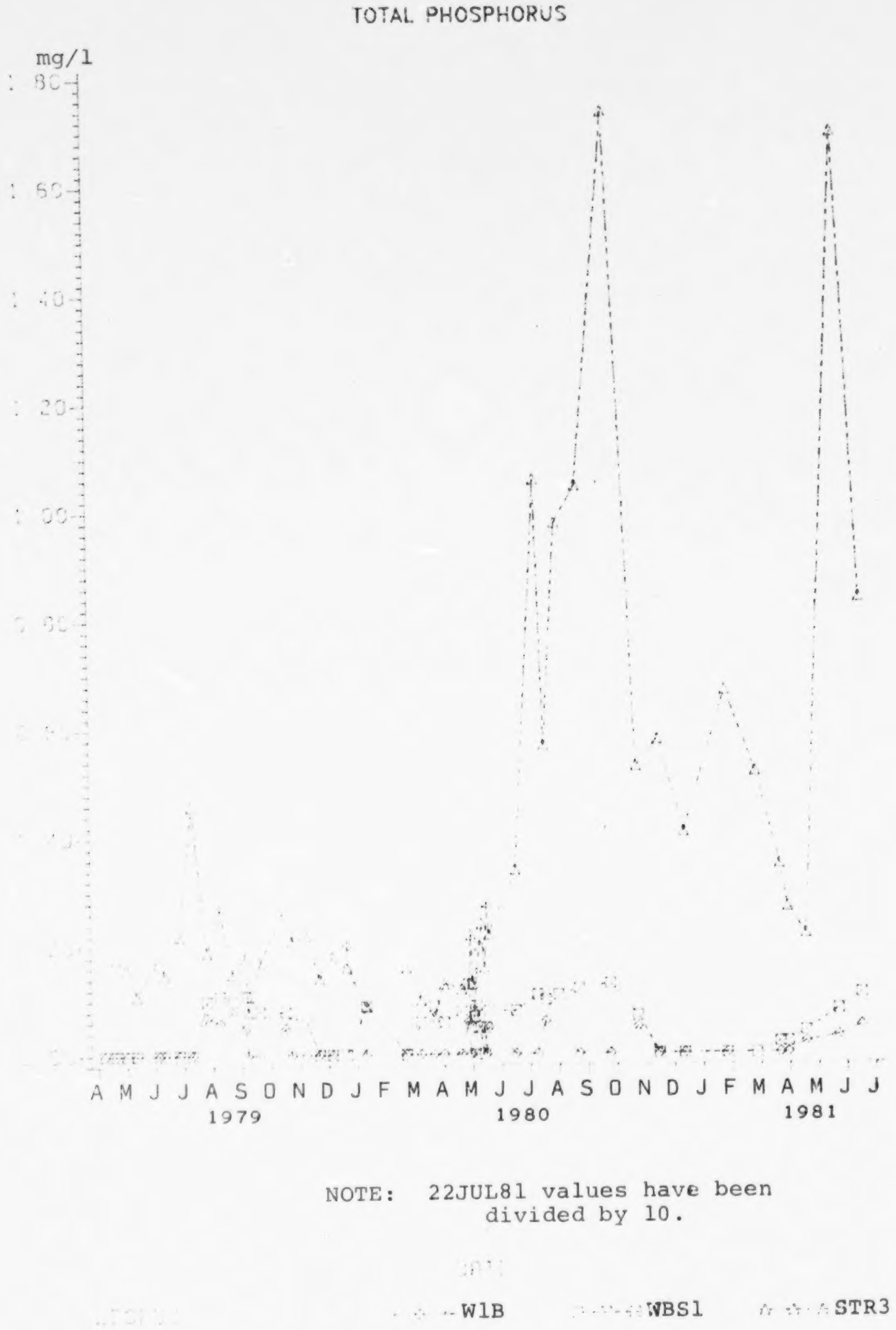
Figure 24. Time-series plot of dissolved oxygen percent saturation at W1B and WBS1.

Total phosphorus (TP) and dissolved orthophosphorus (OP) showed maximum values during the summer months and declined in the winter . Highest concentrations were found in Fox Mill Run. In the marsh region, total phosphorus values were generally indicative of normal enrichment levels, however during the low flow months (July and August) of the study, concentrations averaged >0.10 mg/l, which has been considered a high level of enrichment (Neilson, 1980; Ketchum, 1969) (Figure 25). Downstream station averages were highest in the summer as well (.02 -.05 mg/l), with bottom waters containing greater concentrations than surface waters. Downstream values were moderate throughout the rest of the year.

Silicates were measured biweekly beginning in September, 1979, therefore only 23 months of data will be presented. Highest concentrations were found in the freshwater streams and values generally decreased with distance toward the Bay. Silica is considered to be a semi-conservative nutrient and there was a weak, negative correlation with salinity ($r= -0.64$; $n=744$). Distinct seasonal patterns were observed: peak values for silicates in estuary were recorded in the summer months; low concentrations were seen in the winter until early spring (see Figure 26). Freshwater streams and tidal tributaries registered highest values in the summer and fall months; lowest concentrations were present in the winter and spring. Increased concentrations from baseflow or runoff must account for elevated summer levels. Freshwater dilution, and diatom uptake may explain the lower concentrations present in the estuary during the winter and spring.

Organic nitrogen values consistently comprised the largest fraction of the total measurable nitrogen in the Ware River. Highest values for organic nitrogen and ammonia-nitrogen (thus, the highest total Kjedahl nitrogen values) occurred in the summer; at that time amounts of organic nitrogen greater than 1.1 mg/l were recorded at several places in the estuary during each slackwater survey. Higher concentrations of organic nitrogen were present in the estuary than in the freshwater streams and largest overall concentrations were found at BS6 in the brackish area proximal to the turbidity maximum.

The seasonal pattern for nitrite+nitrate nitrogen levels in the Ware River estuary showed highest values to occur in November through April, or during cold temperature and high flow conditions, and decline during the summer months (Figue 27a-b). The seasonal fluctuation was most likely attributable to increased nitrate following the fall crop harvest, enriching the ground water recharged by the fall rains, since baseflow at the land sites was elevated at this time. Also more nitrate-nitrogen is removed from the water by growing algae in summer than winter. In the tidal and freshwater tributaries, (Figure 27c-d) elevated concentrations occurred during the summer months. Nitrite+nitrate nitrogen concentrations in the tributaries were generally an order of magnitude greater than in the estuarine waters year round. Concentrations decreased toward the Bay, however the



NOTE: 22JUL81 values have been divided by 10.

Figure 25. Time-series plot of total phosphorus, Stations W1B, WBS1, and STR3.

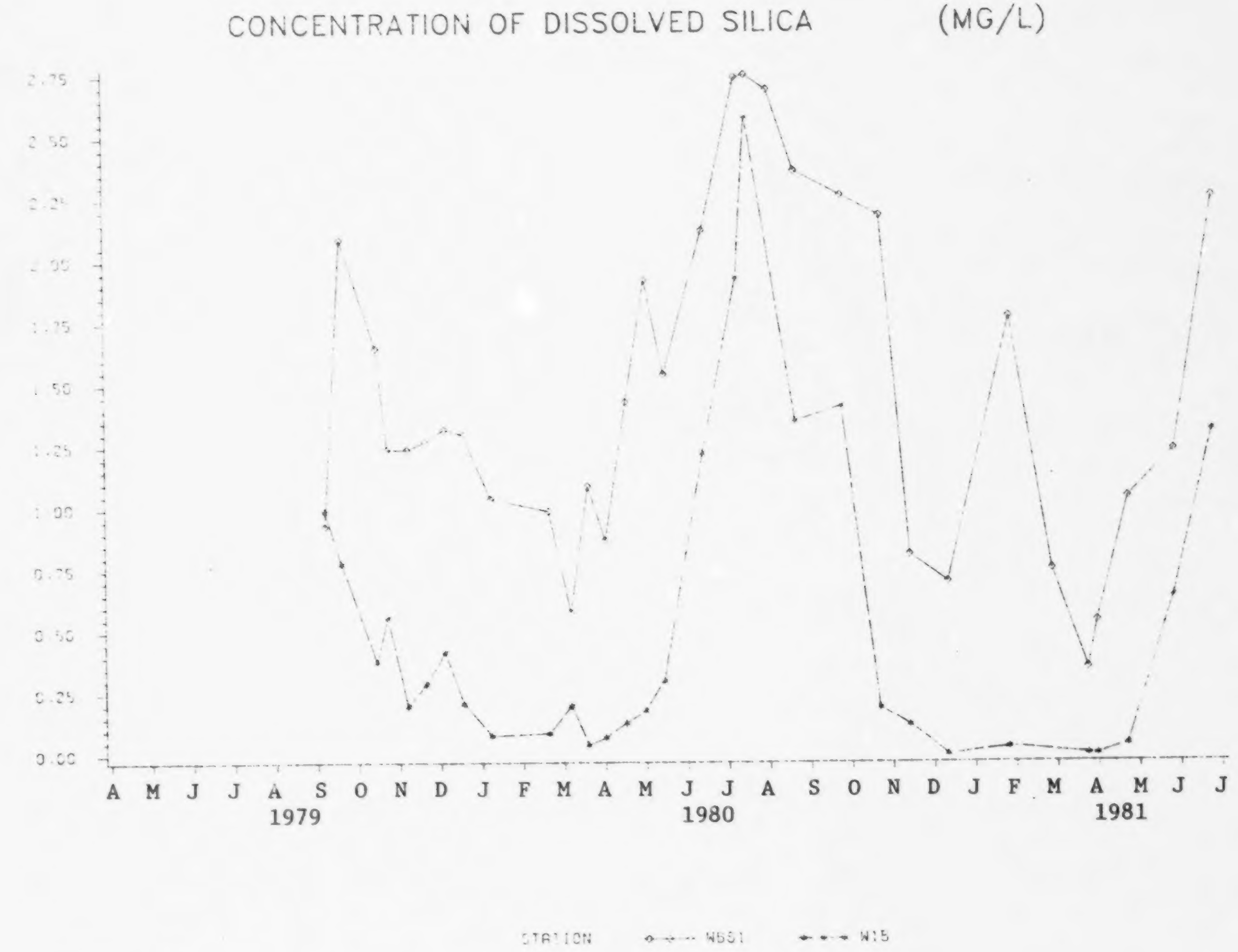


Figure 26. Time-series plot of dissolved silica at WBS1 and W1B.

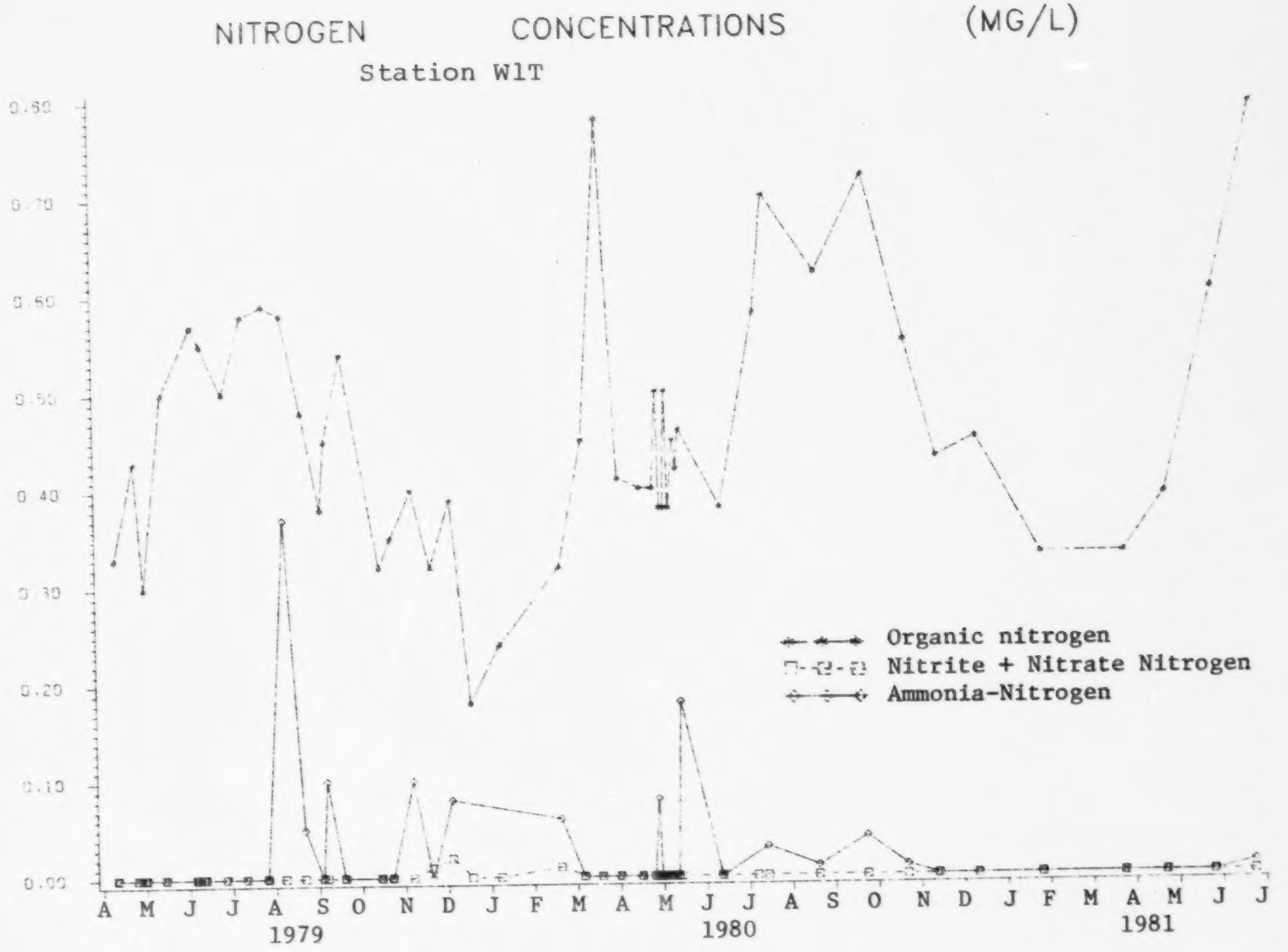


Figure 27a. Time-series plot of nitrogen specie concentrations, Station W1T.

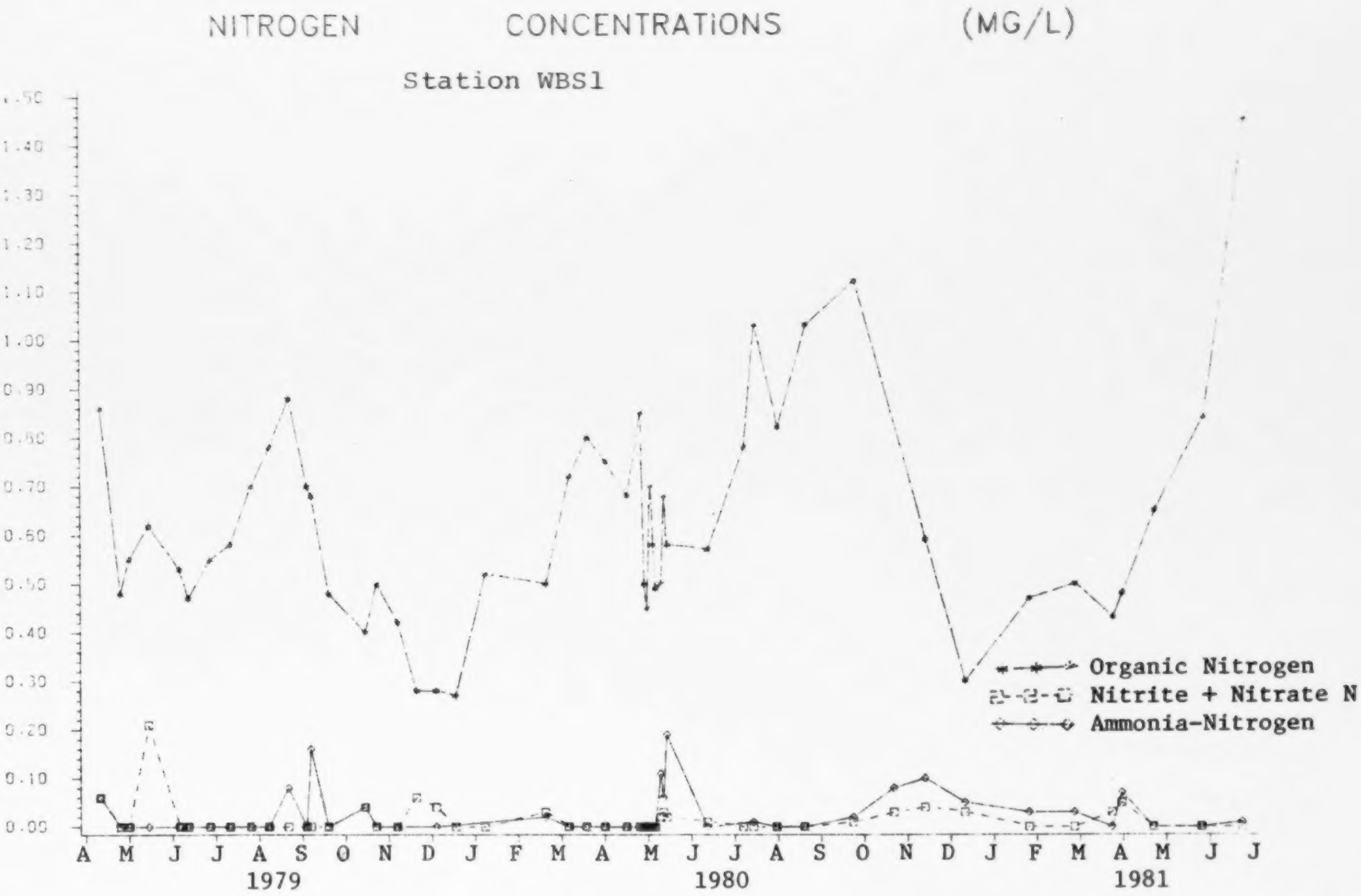


Figure 27b. Time-series plot of nitrogen specie concentrations, Station WBS1.

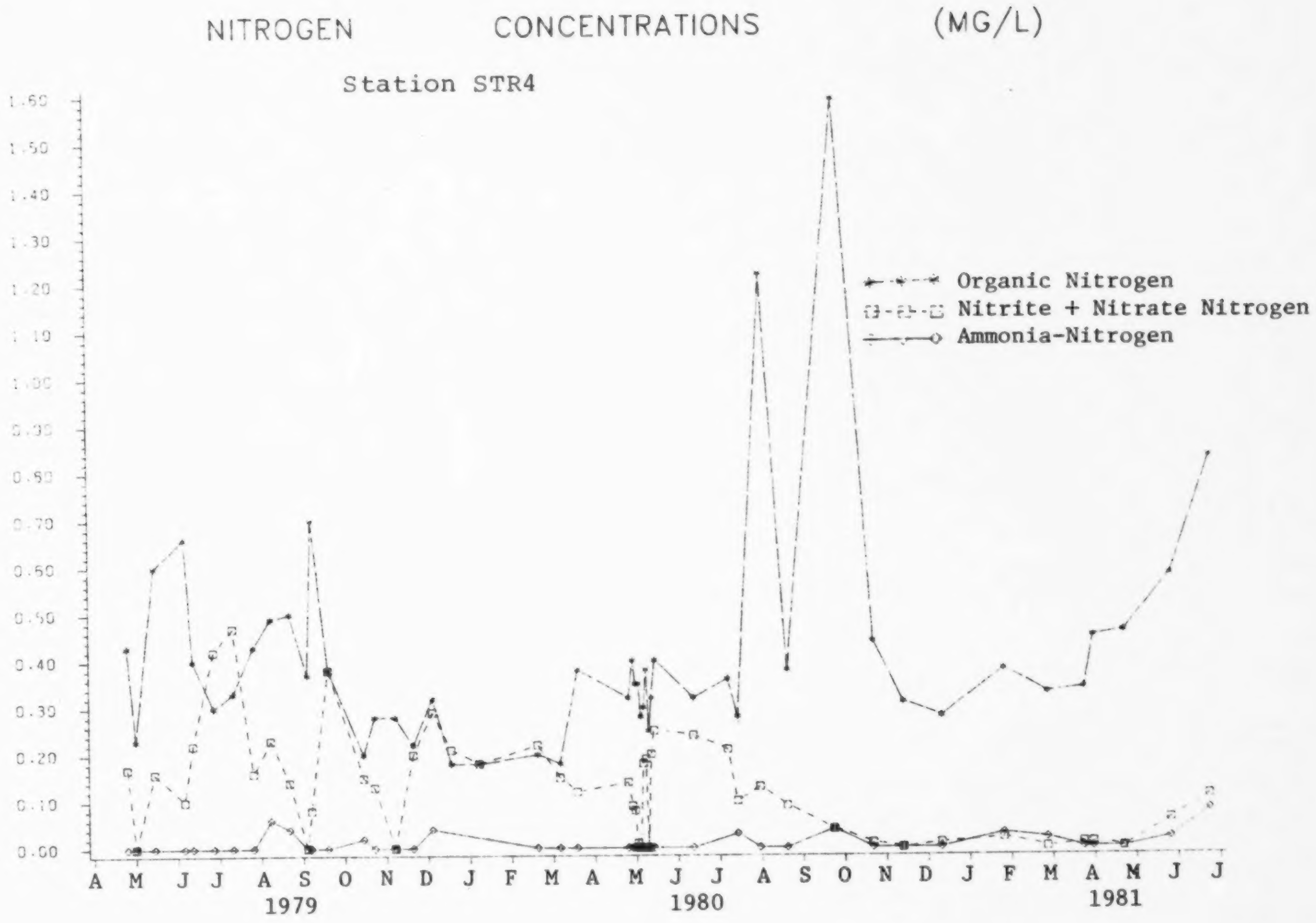


Figure 27c. Time-series plot of nitrogen specie concentrations at Station STR4.

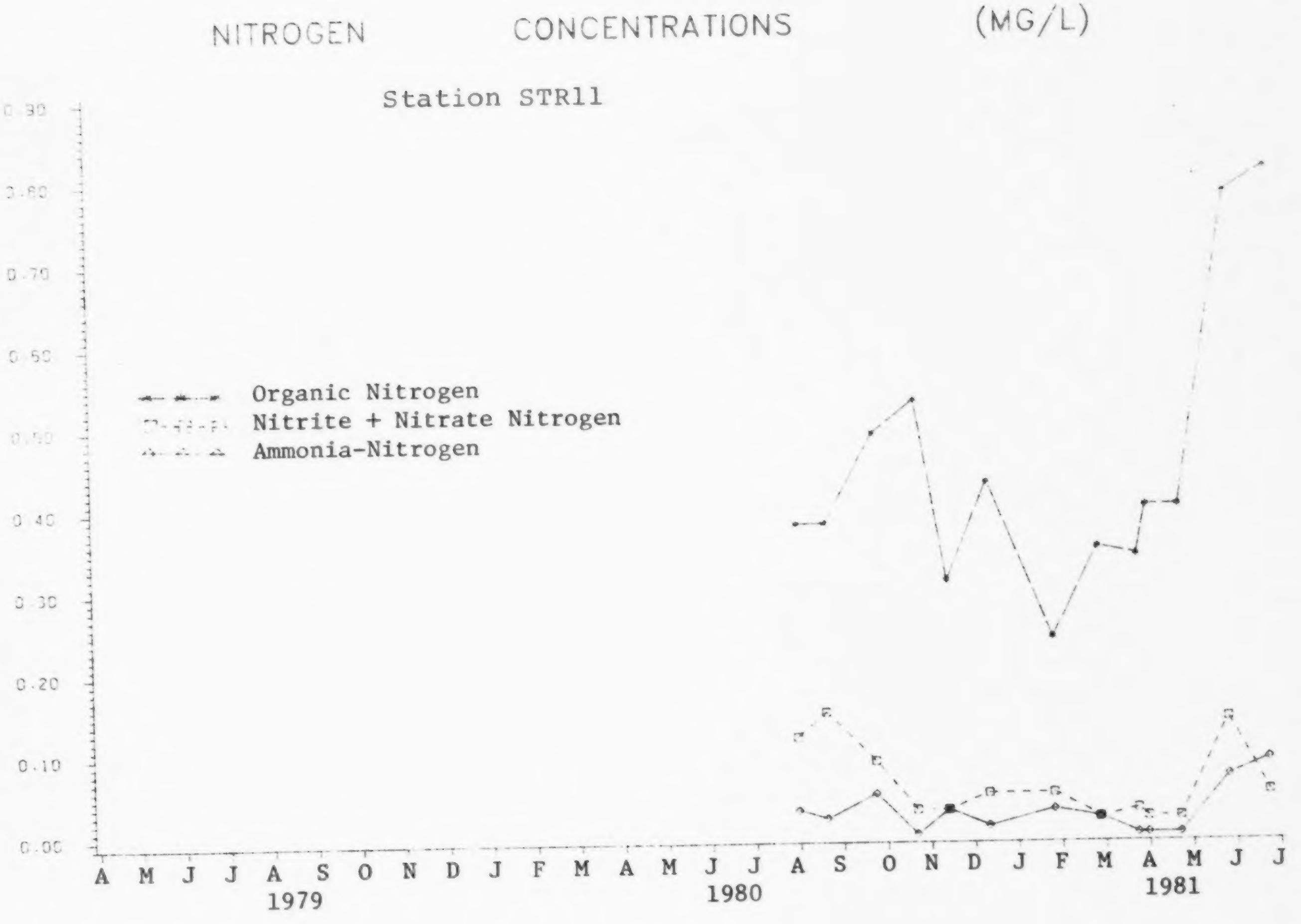


Figure 27d. Time-series plot of nitrogen specie concentrations, Station STR11.

correlation with salinity was poor which indicates the advective dispersion is only one of the factors controlling nitrite-nitrate nitrogen levels.

Monitoring for nitrite-nitrogen began in April 1980; thus a 16 month record is available. Concentrations were generally below detection limit in the estuary throughout the year. Of 527 samples collected, 57 were above the detection limit of 0.01 mg/l. Highest values were present in the tidal and freshwater streams.

Both dissolved and total ammonia-nitrogen were highest in the brackish regions of the estuary, especially in Fox Mill Run. Concentrations peaked during low flow, and warm temperature months (Figure 27a-d).

Total nitrogen to total phosphorus ratios indicated the estuary to be generally phosphorus-limiting throughout the year. There were exceptions, however. Nitrogen-limiting conditions would occur occasionally during the summer months in the downstream, Bay-dominated waters; the freshwater streams and the more brackish regions of the estuary had similar exceptions during the spring. Most notably, FM2 was the only station that was always nitrogen- limited year round. Similar conditions were present upstream at STR3, although during the first year of study (prior to records at FM2), which was also a "wet" year, STR3 became phosphorus-limited on two occasions.

Suspended Solids

Suspended solids data showed no overall seasonal trend. Peak values appeared to be more closely associated with rain events or increased base flow conditions as measured at the USGS gaging station on Beaverdam Swamp, than with the seasons. Elevated concentrations at such times may be due to greater nutrient inputs from increased particulate matter, a factor favoring phytoplankton bloom conditions.

Greatest concentrations of suspended solids were present in the tidal marsh waters on an annual basis, and decreased with distance downstream. Lowest annual values were found in the surface waters near the mouth (W1T, W2T, W3T).

Suspended solids were generally twice as high in the marsh region as in the freshwater stream sites: this probably reflects greater chlorophyll-a levels present in the marsh than in the stream stations (see Figures 21 and 28).

Because of the low concentrations present in the top waters, it appears that the Ware River subestuary may act as a sediment trap and thus is not exporting suspended solids into Chesapeake Bay.

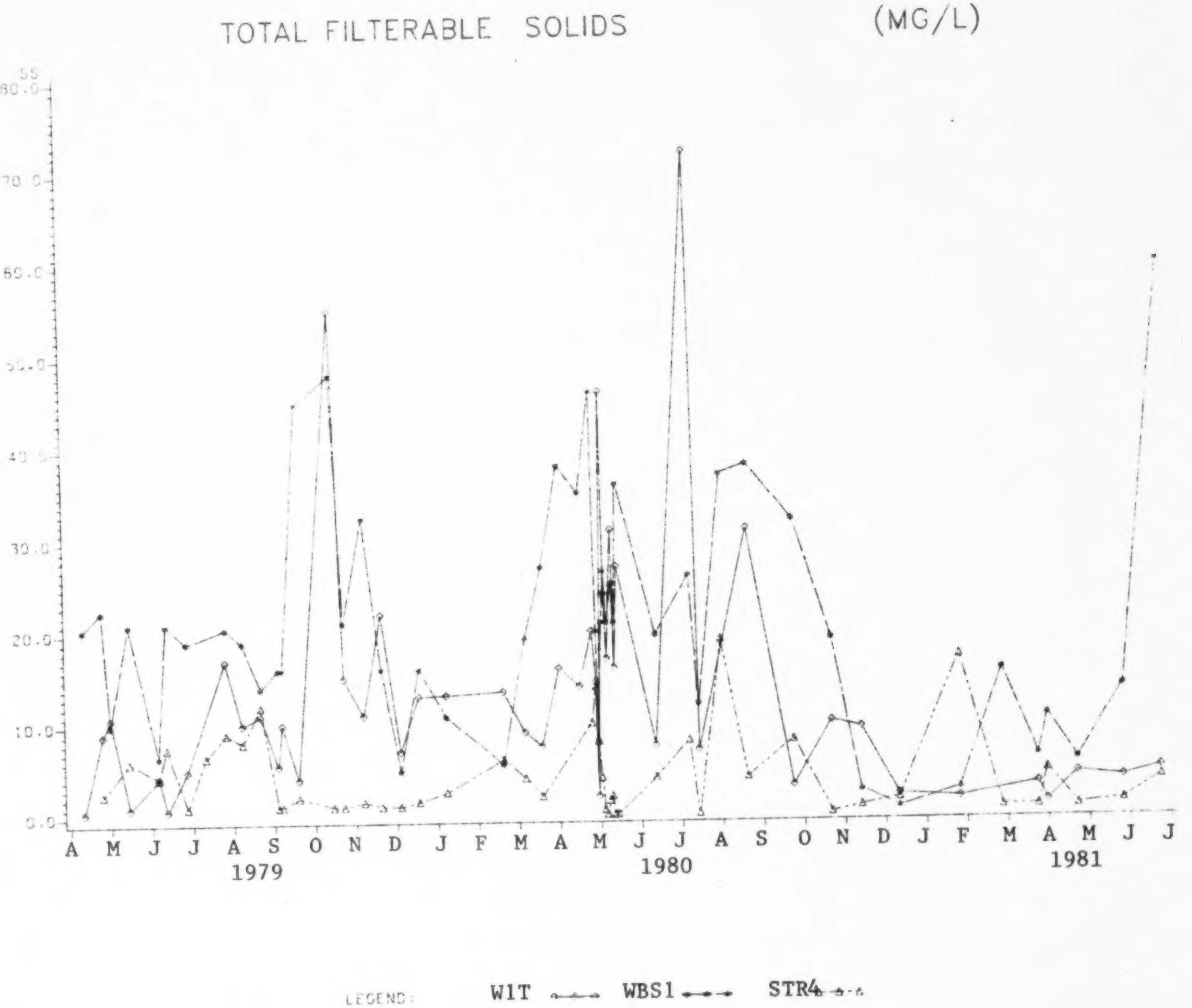


Figure 28. Time-series plot of total filterable solids at WIT, WBS1, and STR4.

2.4 SPRING SURVEY 1981

During the spring seasons of 1979 and 1980, distinct increases in chlorophyll-a concentrations were noted in the Ware River estuary. Chlorophyll-a levels of 25-35 ug/l were observed which is several times the annual average of 9.5 ug/l. The blooms were concomitant with sharp increases in water temperature.

A spring sampling survey was designed in early 1981 to see if a chlorophyll-a maximum would once again occur. Frequent sampling was planned so as not to randomly "hit or miss" such ephemeral phenomena; sampling was to commence before water temperatures warmed to 10 C since most biological activity occurs thereafter.

On March 6, water temperatures were recorded at 6.5 C (Figure 29). Two stations in the upper estuary were selected and outfitted for continuous monitoring using automatic samplers at that time. Composite samples (200-ml aliquots of water drawn every 30-45 minutes) were collected three times weekly and analyzed for a suite of nutrient parameters (temperature, salinity, dissolved oxygen, suspended solids, chlorophyll-a, pheophytin, silica, orthophosphate filtered, total phosphorus, dissolved and total Kjeldahl nitrogen, filtered ammonia nitrogen, filtered nitrate-nitrogen and filtered nitrite-nitrogen). Phytoplankton enumerations and identifications were conducted simultaneously. This sampling schedule continued for 3 months, lasting unitl June 5, 1981.

Physical Processes

The mean salinity of station Goshen (rivermile 5.0) was 20.9% during the period and station Pig Hill (rivermile 6.3) was 14.6% (see Figure 30). Temperature was not significantly different between the two stations and rose 20 degrees C in the 3 month period, from 6.5 C to 26 C.

Biochemical Processes

Dissolved oxygen (expressed as percent saturation of dissolved oxygen) was significantly higher at Goshen than Pig Hill and became supersaturated on occasion, particularly at the time when chlorophyll-a levels were at a maximum (Figure 31, May 15-25). Supersaturated oxygen conditions were not noted at Pig Hill, although both stations followed a similar pattern during the period.

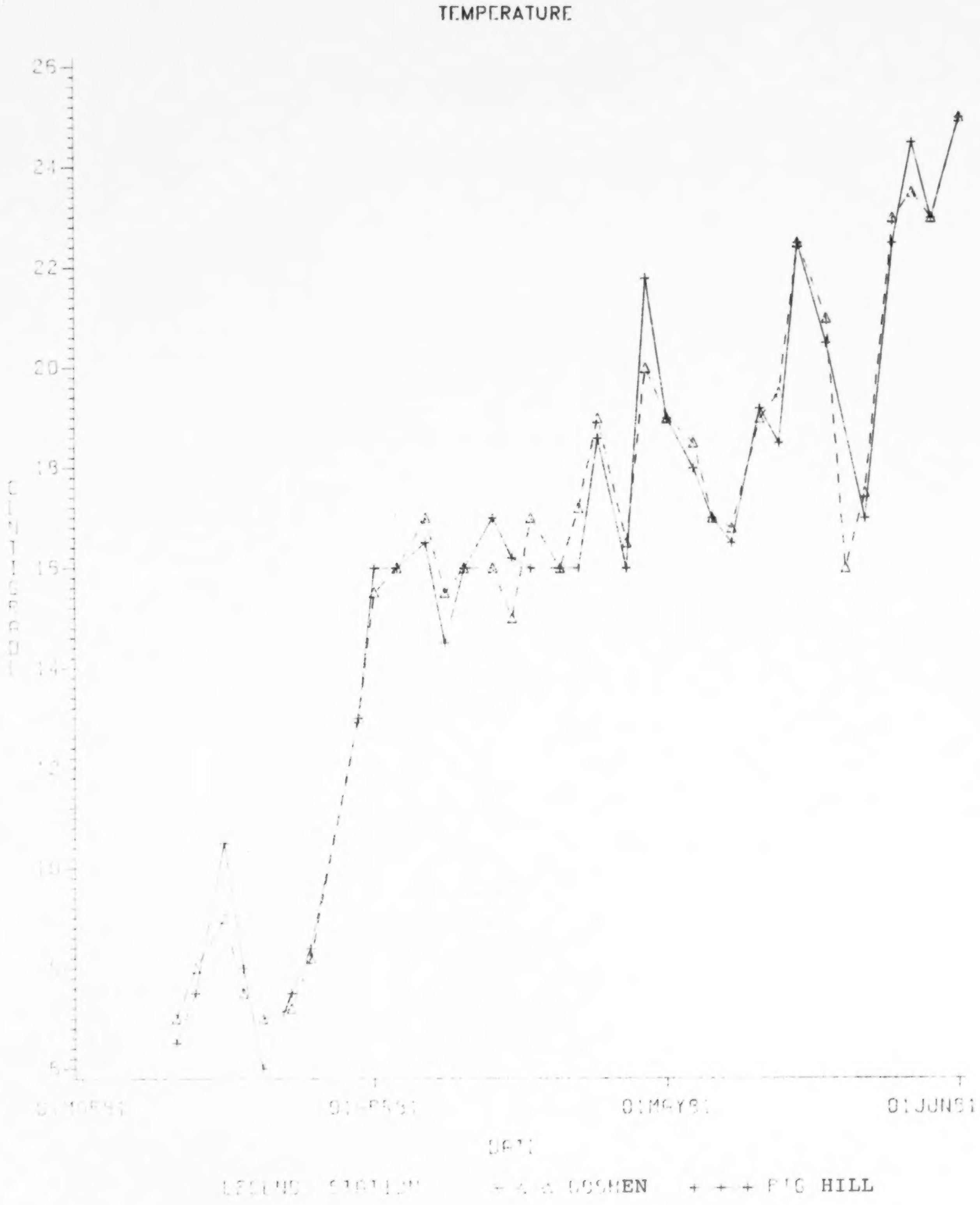


Figure 29. Time-series temperature plot during 1981 Spring Survey.

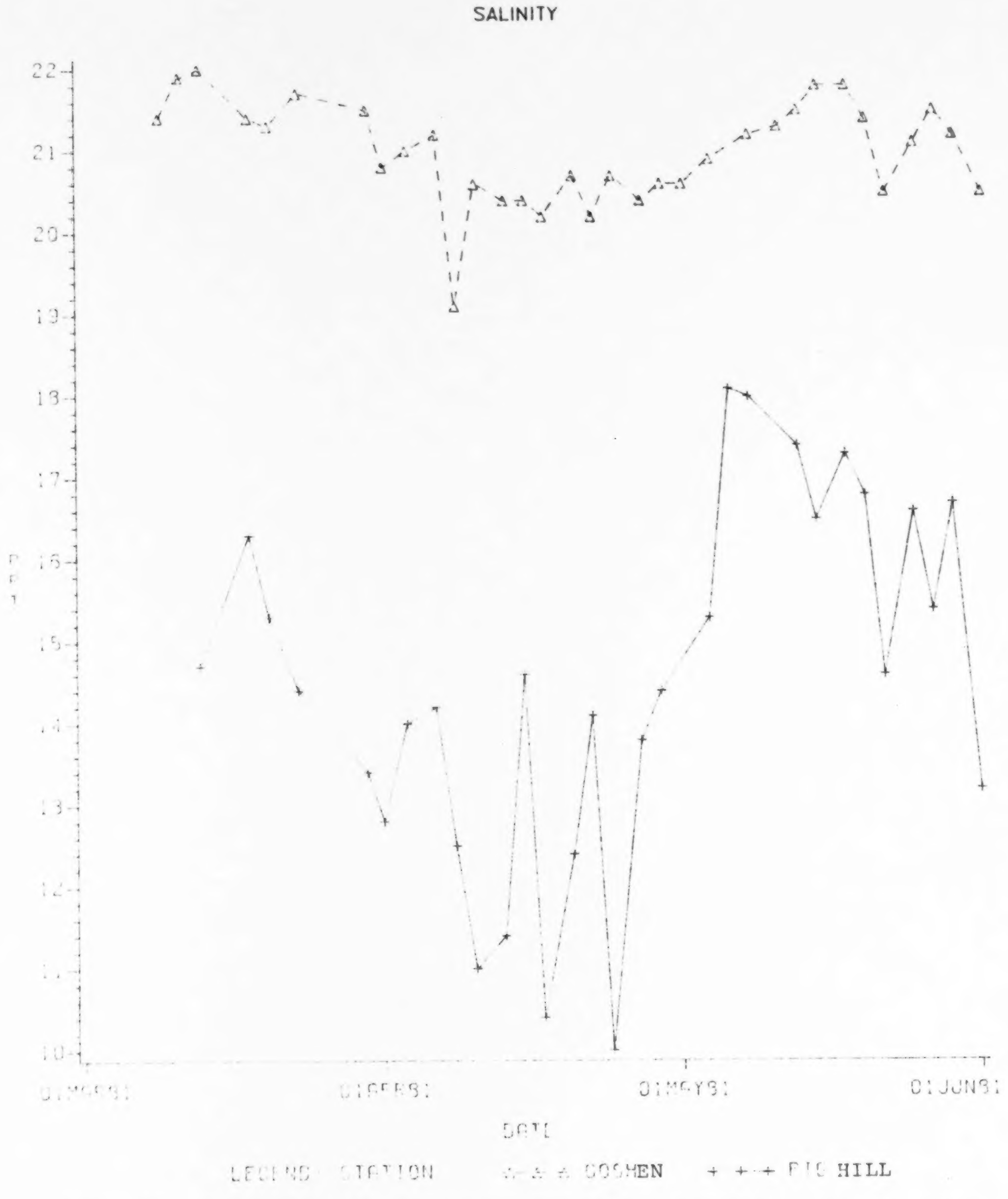


Figure 30. Time-series plot of salinity concentrations during 1981 Spring Survey.

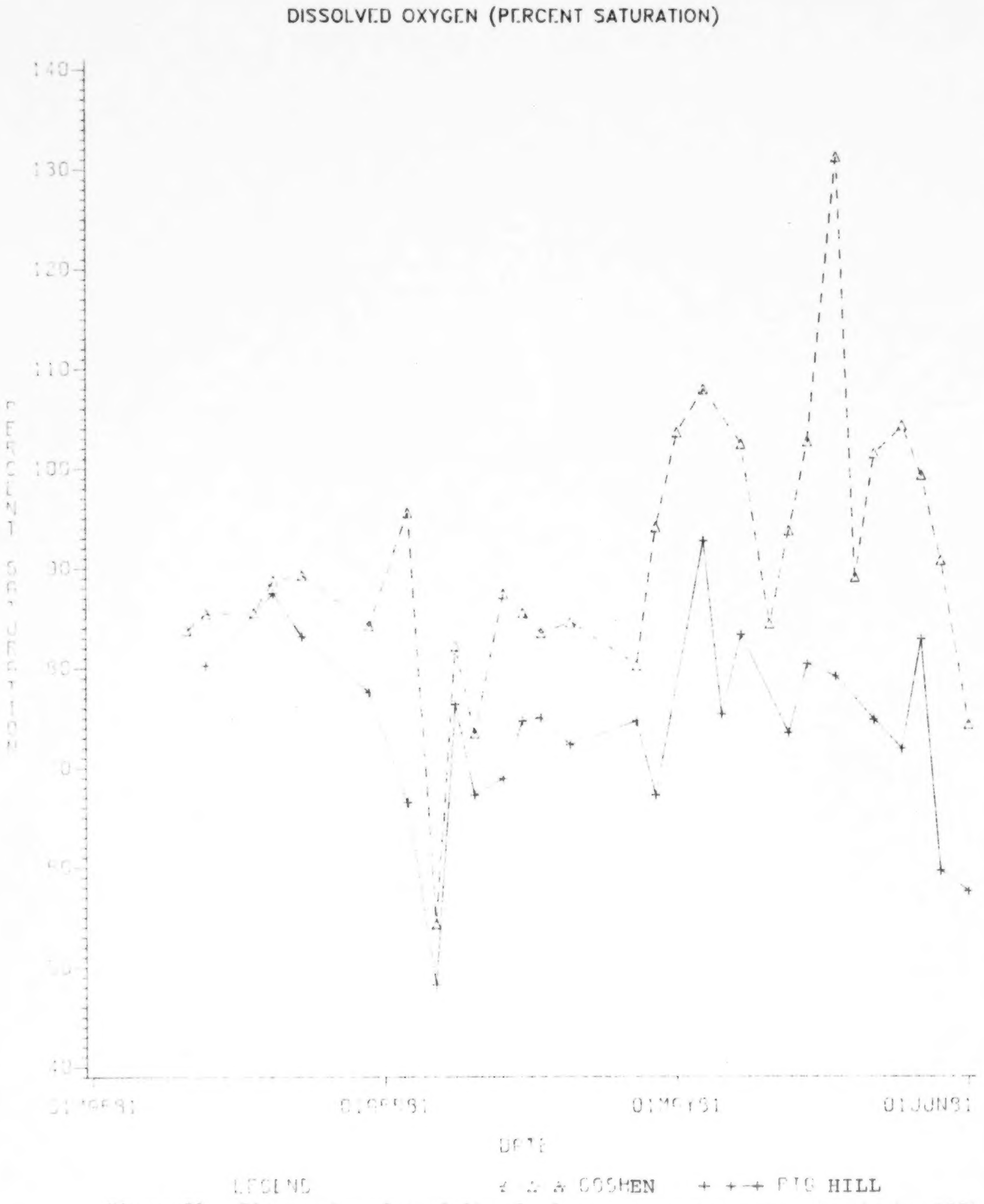


Figure 31. Time-series plot of dissolved oxygen percent saturation during 1981 Spring Survey.

As might be expected, Pig Hill had significantly higher nutrient concentrations than Goshen for total phosphorus, Kjeldahl nitrogen (both total and dissolved forms), silicates and suspended solids. Combined with the knowledge that oxygen levels were greater at Goshen than Pig Hill this tends to imply that the marsh region of the estuary was acting as a source of nutrients and that overall nutrient concentrations declined with distance downstream. Once again dilution of nutrient-rich marsh waters by tidally driven Bay waters in determining estuarine water quality was evidenced.

Total nitrogen levels were roughly the same at the two stations (Figure 32a and b) and slightly increased during the study period. Particulate and organic-nitrogen predominated throughout the period. There was not a significant difference in dissolved inorganic and organic nitrogen between stations, however significantly greater amounts of ammonia-nitrogen were present at Pig Hill than Goshen. Nitrate-nitrogen was present until mid- April and declined thereafter. Overall total nitrogen seemed to increase during the period at both stations.

There was a significant diference in total phosphorus between the 2 sites. Very little orthophosphorus was detected during the study, (Figure 33a and b) therefore the majority of measurable total phosphorus was in the organic and particulate fraction. Similar to nitrogen, concentrations tended to slightly increase with time.

TN:TP ratios

Orthophosphates were generally below detection limit at both stations throughout the study period therefore atomic ratios for dissolved inorganic nitrogen:dissolved inorganic phosphate were not calcuable. TN:TP ratios could be calculated, and both stations had high ratio values (over 16) which tends to indicate that the system was phosphorus limiting. Overall, TN:TP ratios were lower at Pig Hill than Goshen, (Figure 34) and values at both stations appeared to slightly increase with time.

Chlorophyll-a values were very similar at the two sites and rose gradually from a low of less than 2 ug/l during the period. Concentrations peaked on 22 May 1981 (Figure 35) and returned to a more typical value of 10 ug/l thereafter. Although values are subject to much temporal and spatial variation, the 1981 spring chlorophyll-a values appeared to differ from the two previous year's values in both quantity, quality and time of year:

Spring 1979: High values were only present at the downstream stations (> 35 ug/l in April). Elevated concentrations durated through the next 2 slackwater surveys. No bloom was measured in the brackish area until June (27 ug/l).

Spring 1980: Bloom conditions were present all over the estuary by March 19th, (> 30 ug/l). Similar to the previous spring, elevated concentrations were found at successive samplings.

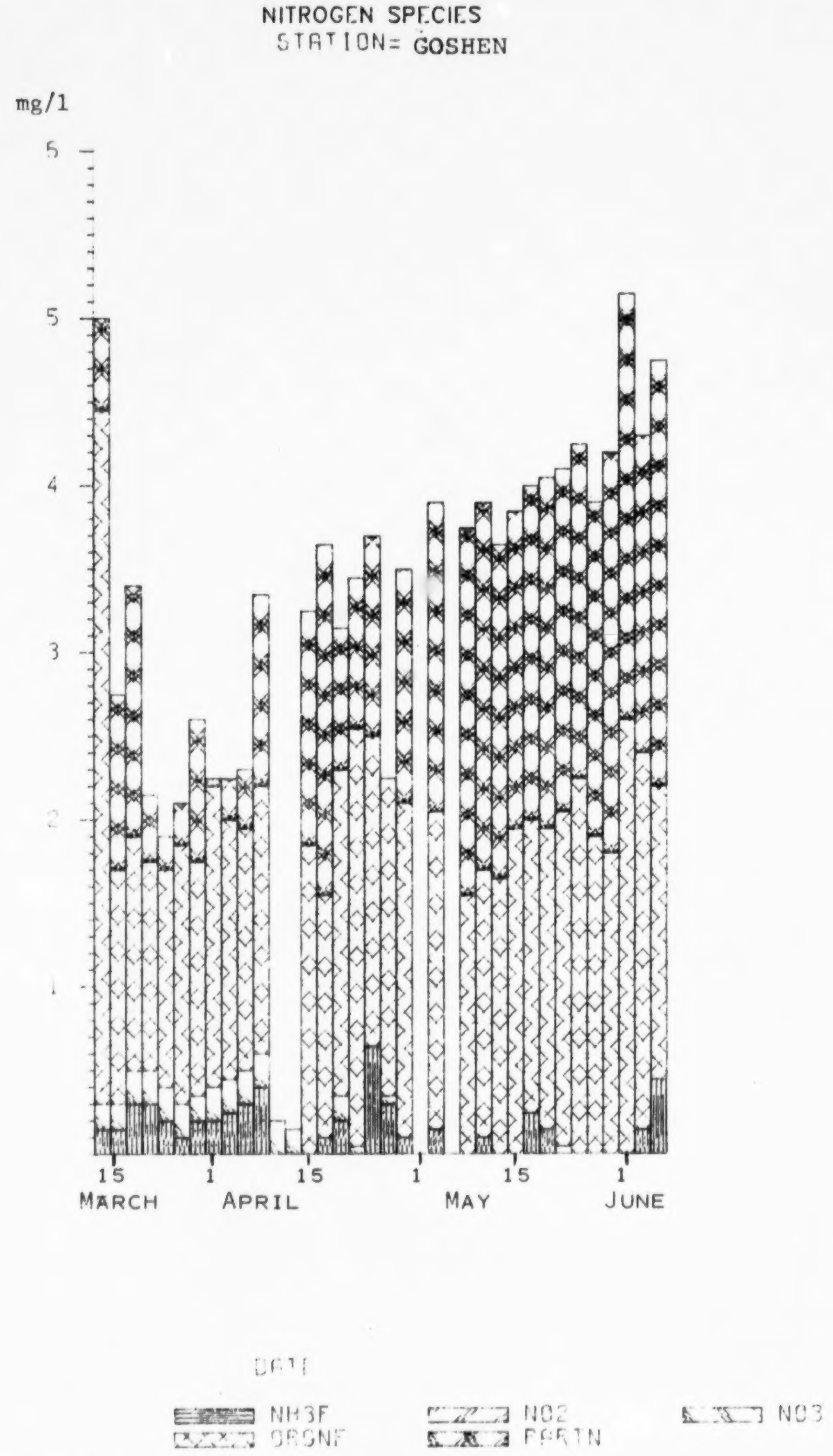


Figure 32a. Time-series histogram of nitrogen specie concentrations at Goshen during 1981 Spring Survey.

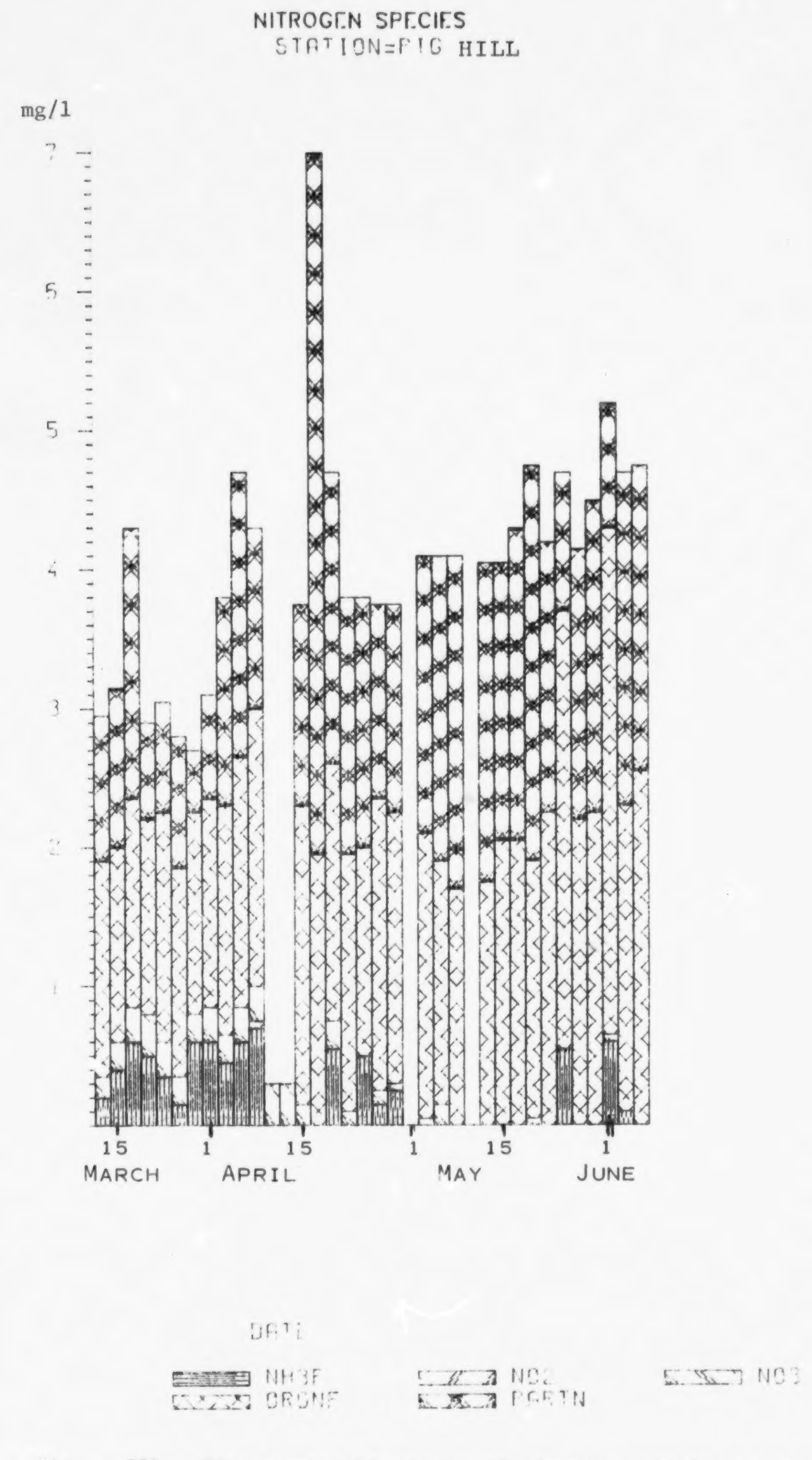


Figure 32b. Time-series histogram of nitrogen specie concentrations at Pig Hill during 1981 Spring Survey.

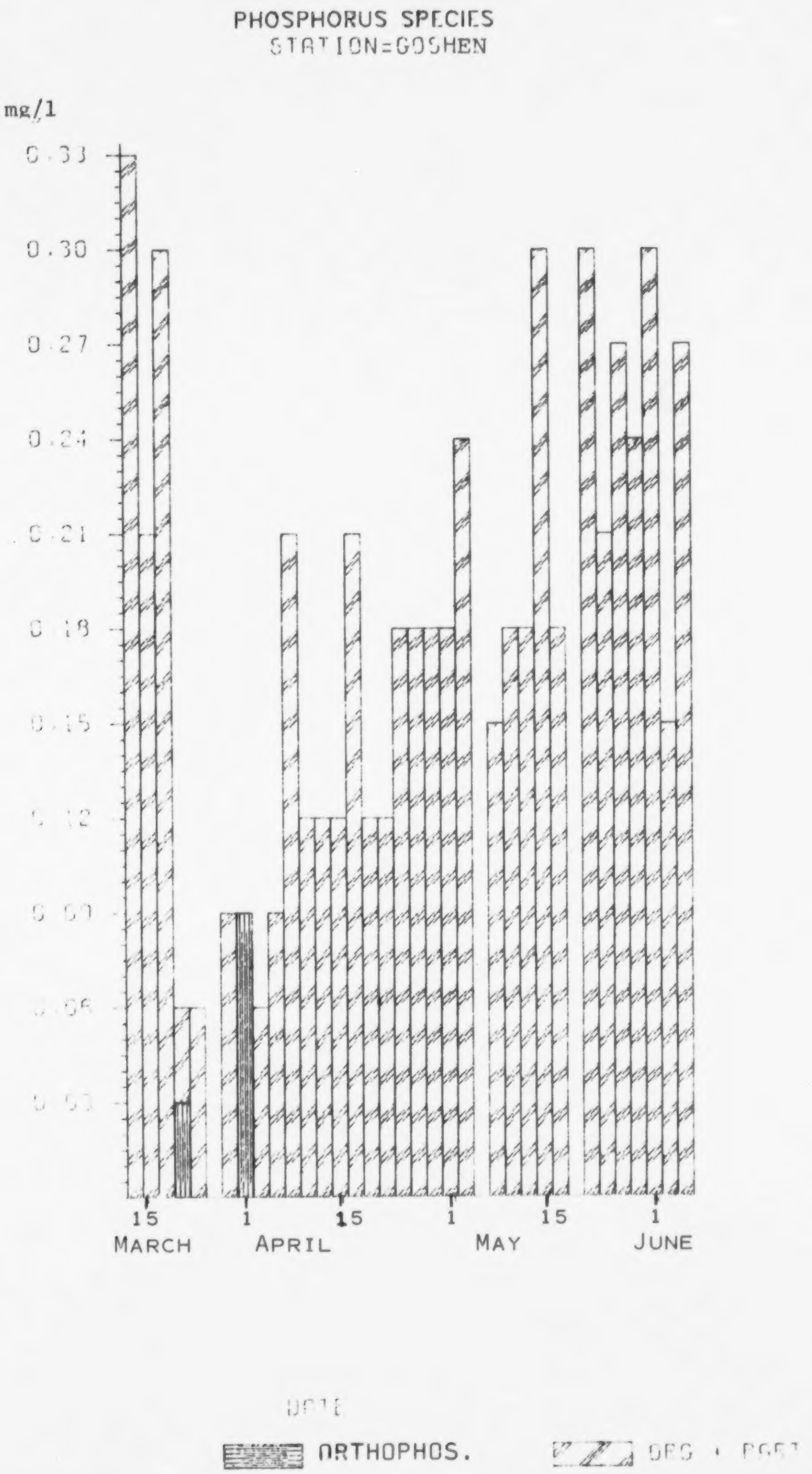


Figure 33a. Time-series histogram of phosphorus specie concentration at Goshen, 1981 Spring Survey.

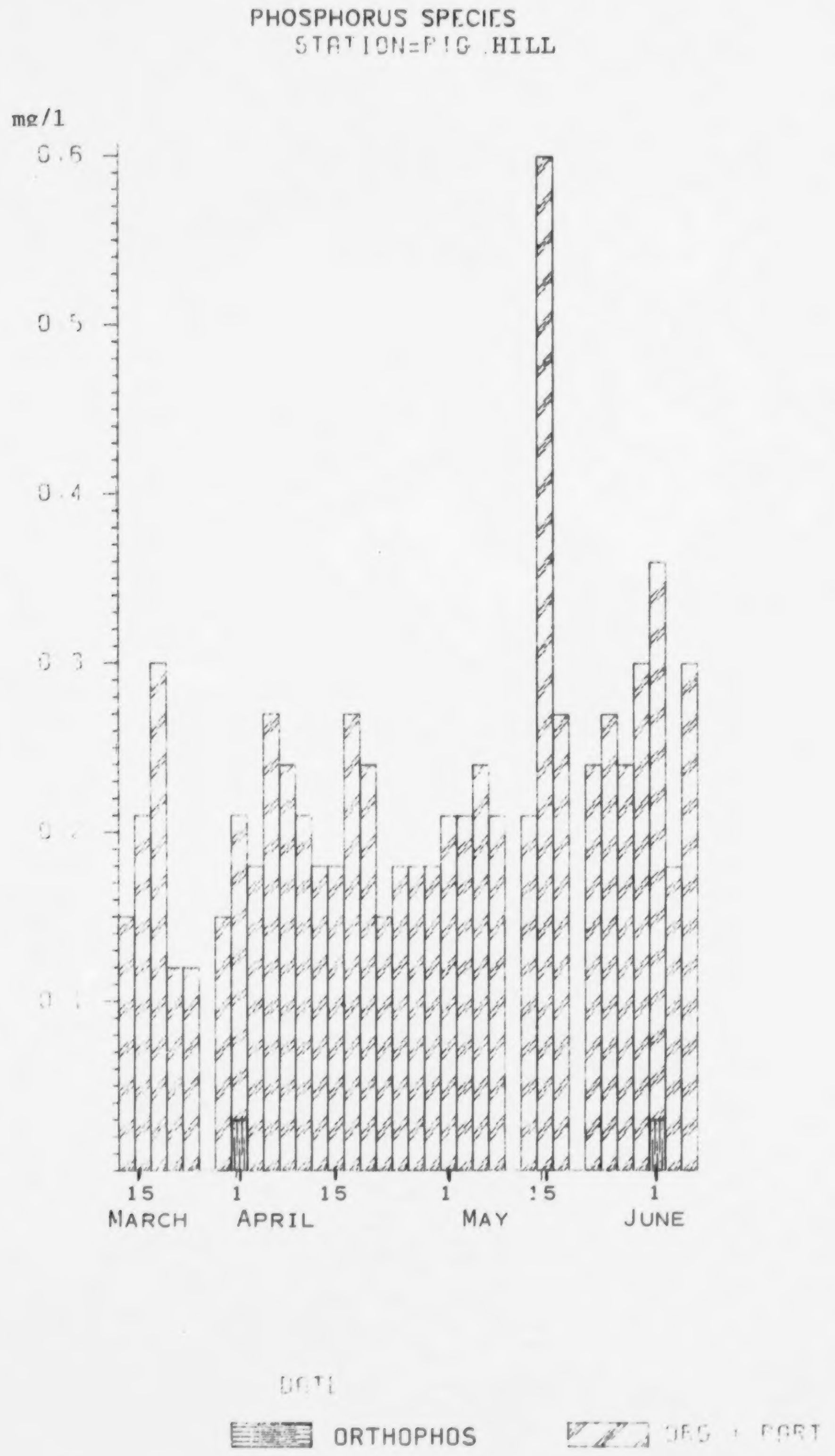


Figure 33b. Time-series histogram of phosphorus specie concentrations at Pig Hill, 1981 Spring Survey.

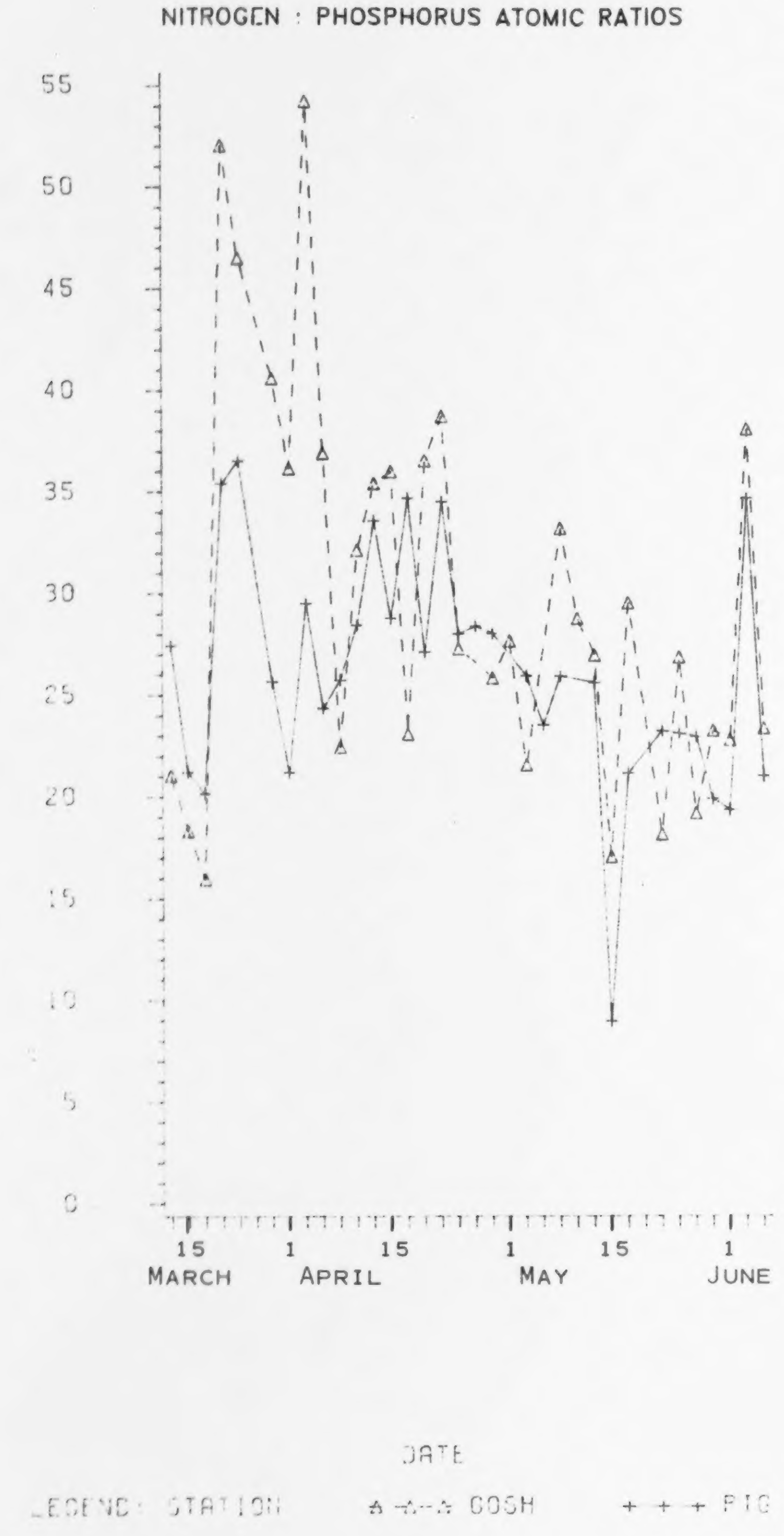


Figure 34. Time-series plot of TN:TP ratios during 1981 Spring Survey.

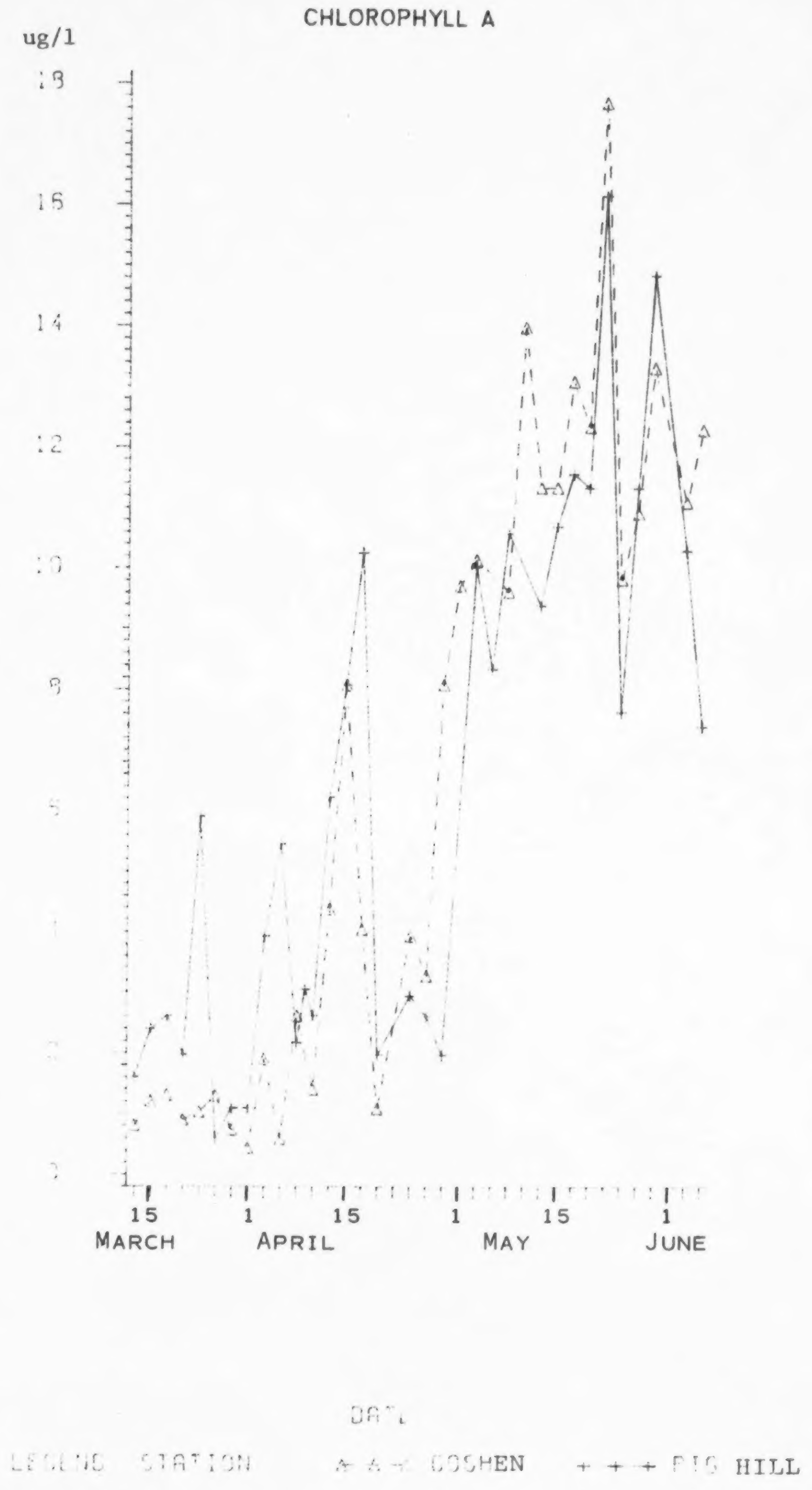


Figure 35. Time-series plot of chlorophyll-a concentrations during 1981 Spring Survey.

Peak values appeared to durate longest in the brackish area, especially at FM2 and BS8.

Spring 1981: Chlorophyll-a values remained low, and did not rise above 10.0 ug/l in the estuary until May 26th. At that time, highest values were at W5 (15.0 ug/l). Thereafter, values were greatest in FM2 and BS8.

Phytoplankton Quality

Green flagellates (Chlorella) were the dominate organism when the chlorophyll-a maximum occurred in the spring of 1981. In previous springs, diatoms had been the dominant organism. It should be noted that diatoms were persistant throughout the period in 1981 and were next in order of frequency followed by cryptomonads (Figure 36a-b). Dissolved silica was not highly correlated with either diatom cell counts or salinity (Figure 37). Silicate concentrations at Goshen were elevated prior to peak diatom counts and remained somewhat low thereafter, which suggests uptake by plankton.

Rainfall:

Rain and freshwater flow as measured at the USGS gaging station on Beaverdam Swamp were below average during the spring survey (Figure 39). Rainfall of one-half inch or more tended to produce increased suspended solids (but decreased nutrient levels) in the study area. The response was most dramatic at Pig Hill (Figure 38). Similarly, drops in salinity following 0.5 inch rains could be seen best at Pig Hill.

The 1981 Spring Survey compared with the overall spring trend data of 1979 and 1980 as follows: temperatures were slightly lower, salinity and percent dissolved oxygen were somewhat higher than the preceeding 2 springs.

Chlorophyll-a, silica, suspended solids, and total phosphorus concentrations were somewhat lower in 1981, whereas total Kjeldahl nitrogen (both total and dissolved forms), ammonia-nitrogen and nitrite+nitrate nitrogen were slightly higher. Interestingly enough, the spring 1981 standard deviations were similar if not slightly higher than the 1979-80 spring periods even though automatic samplers, which tend to eliminate variability in collection techniques, were used to collect the data. Higher variation may have resulted from 1) the lowering of detection limits during the second year of study and 2) the fact that the automatic samplers composited water throughout the tidal cycle, as opposed to sampling at highwater slack only.

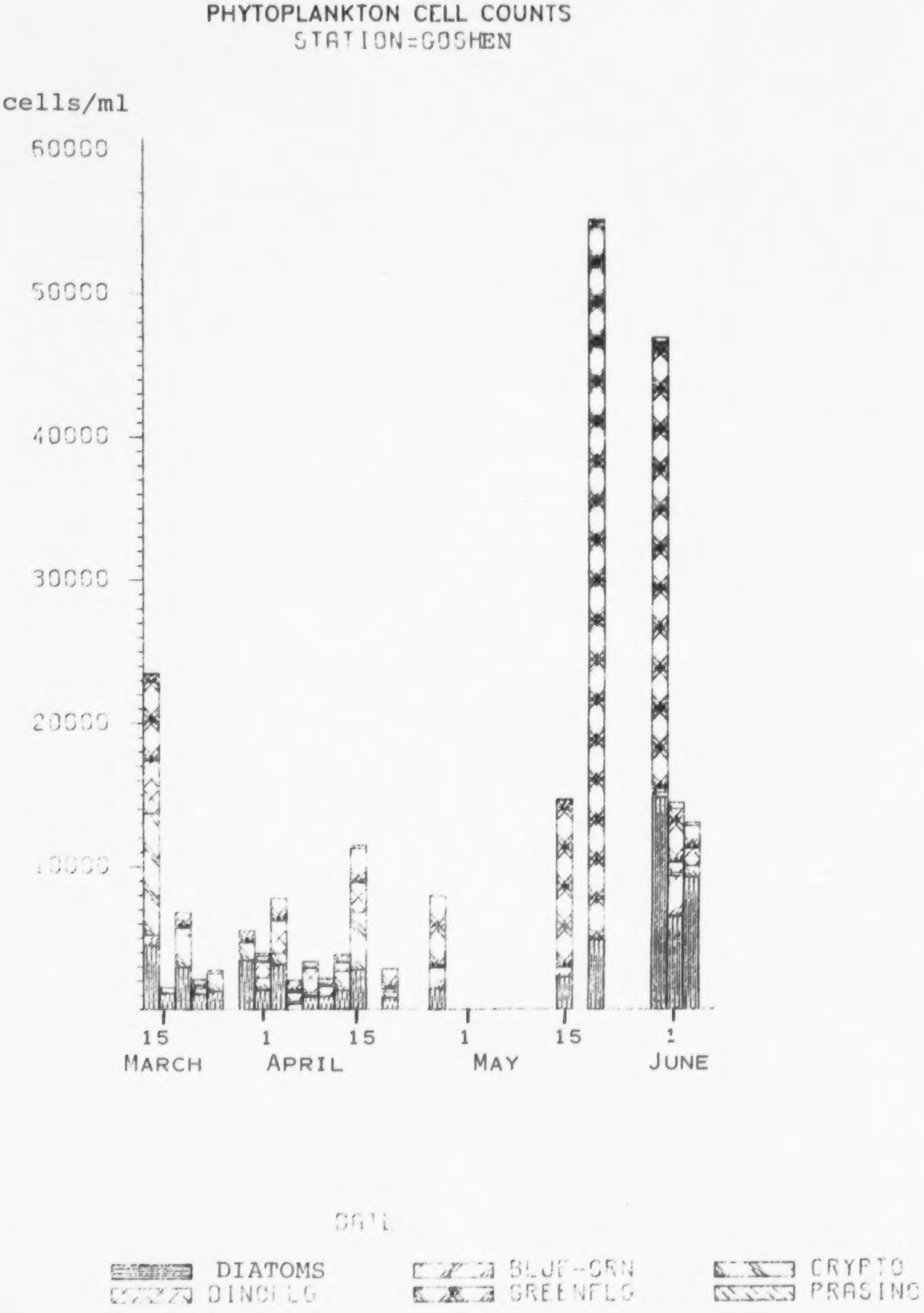


Figure 36a. Phytoplankton cell counts at Goshen during 1981 Spring Survey.

GREEN FLAGELLATE COUNTS WERE DIVIDED BY 100

ON 20 MAY 1981

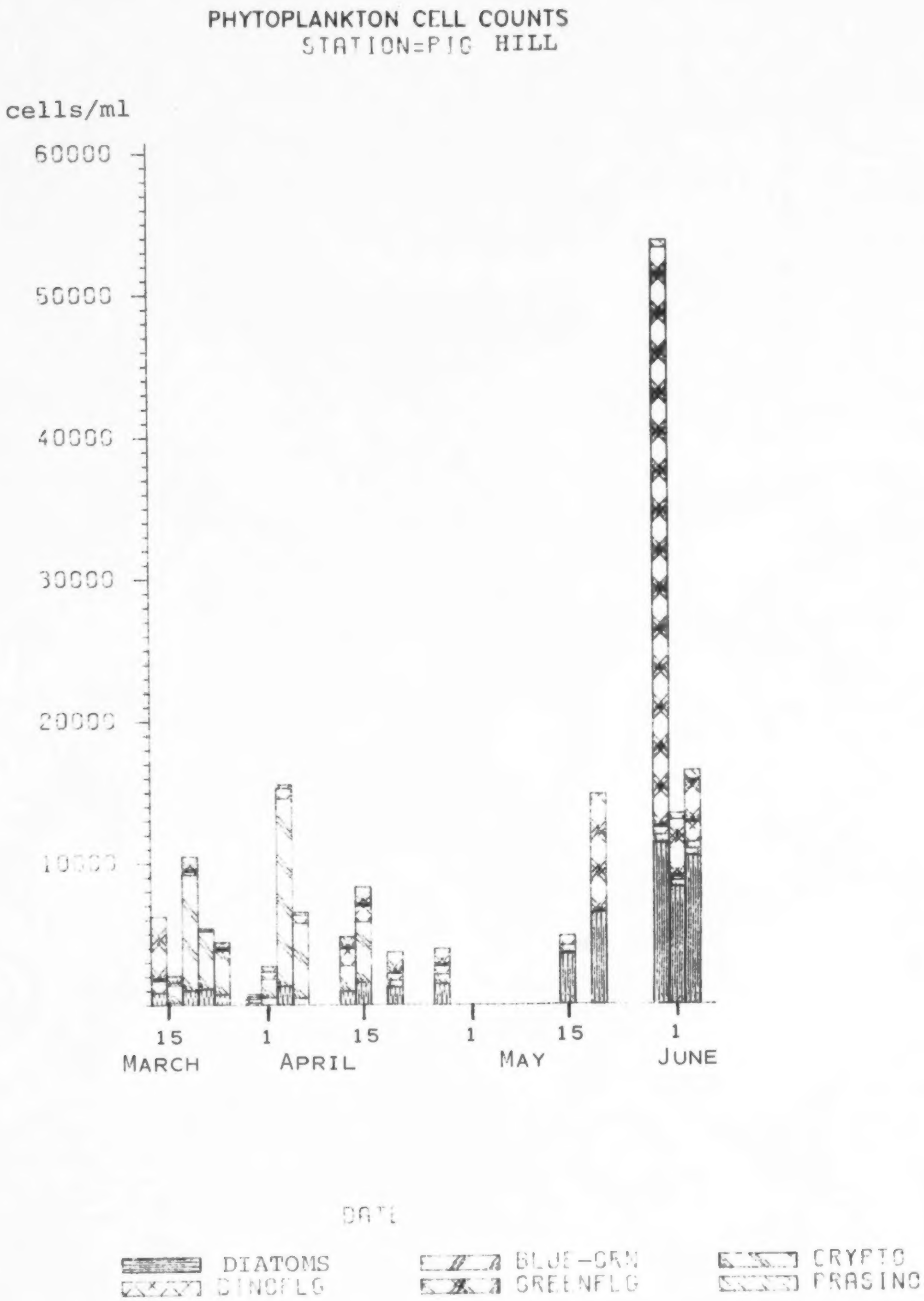


Figure 36b. Phytoplankton cell counts at Pig Hill during 1981 Spring Survey.

GREEN FLAGELLATE COUNTS WERE DIVIDED BY 100

ON 20 MAY 1981

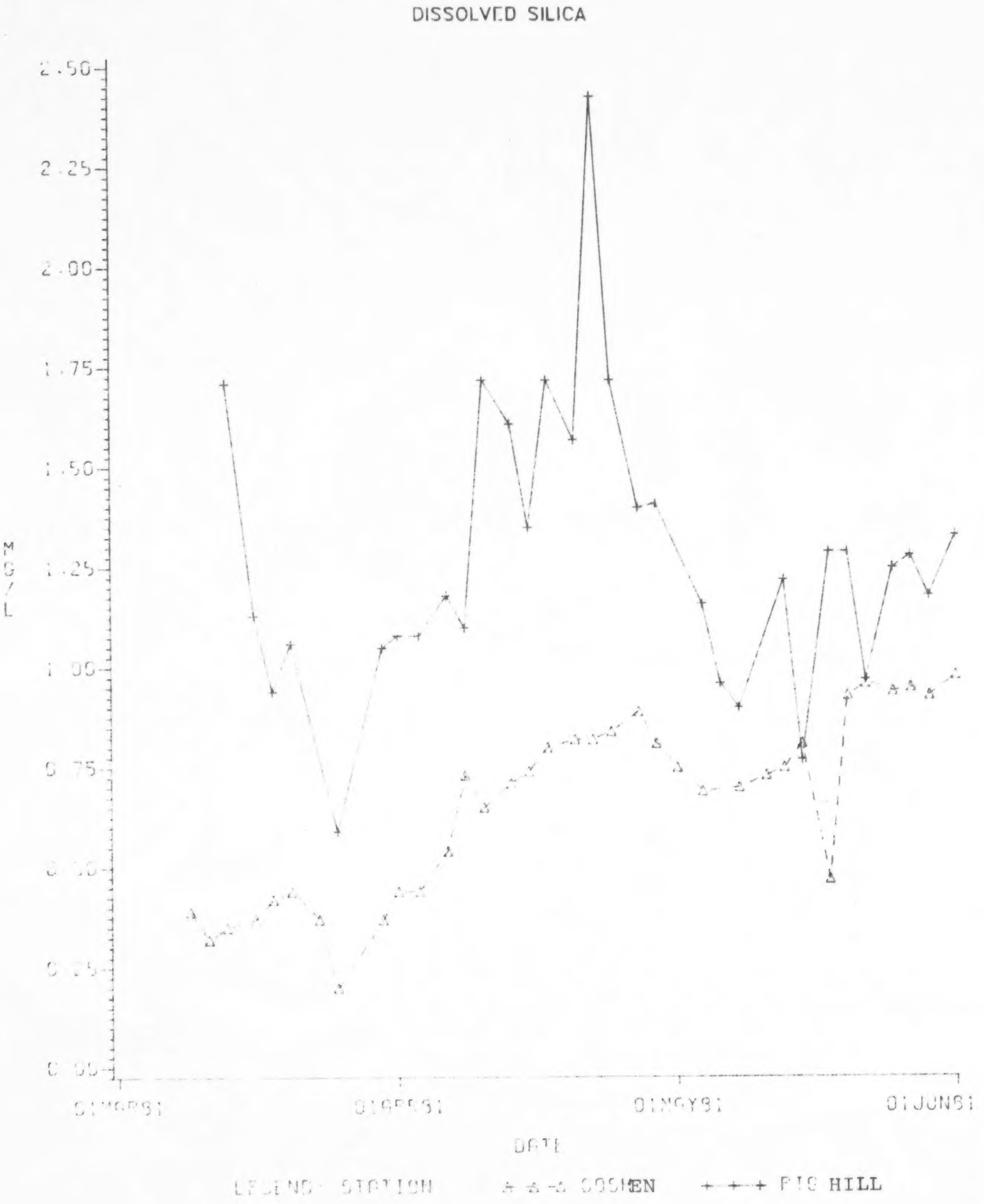


Figure 37. Time-series plot of dissolved silica concentrations during 1981 Spring.

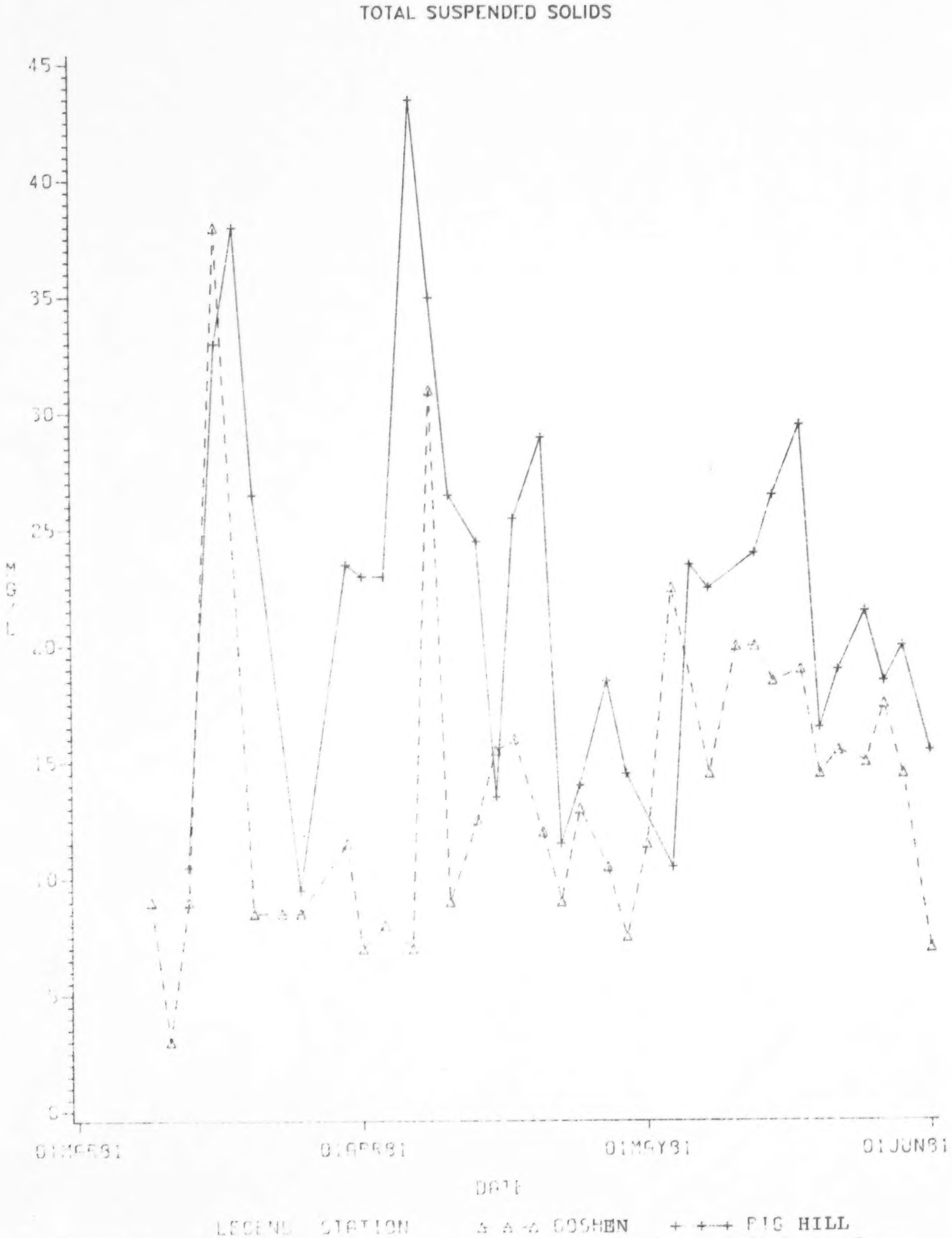


Figure 38. Time-series plot of total suspended soldis during 1981 Spring Survey.

2.4.1 TWO DAY vs. ONE MONTH SAMPLING INTERVALS

How representative are data collected once a month in the Ware River? By calculating monthly averages for spring composite samples a comparison was made between data collected every 2 days (although composited during the period) vs. data collected once per month. Comparisons were made at both stations for the 3 month period and are summarized in Table 3.

Interestingly enough, the variation between automatic sampler data collection and slackwater grab-sampling methods was less than the seasonal variation. Exceptions to this were suspended solids, and chlorophyll-a concentrations. Suspended solids showed the greatest discrepancy; in all case the automatic samplers obtained higher values than the slackwater grabs. This may be due to the fact mentioned above, that composite samples contained water collected over the entire tidal cycle as opposed to grabs obtained at (high) slackwater only. Chlorophyll-a data varied less than suspended solids; however, chlorophyll-a varied in both directions, therefore it is inconclusive whether either technique overestimates or underestimates phytoplankton populations, or whether the difference represents environmental or diurnal variations.

Overall, composite values tended to be slightly higher than grab sample values for other parameters as well (Table 3). Such discrepancies can be attributed to either spatial differences, or the effects of sampling throughout the tidal cycle. Synoptic sampling in the Ware River during Intensive surveys has shown very little variation laterally and longitudinally in the estuary; however temporal differences exist, especiallly in the upstream area. Therefore, it is presumed that differences in values are attributable to diurnal factors such as tidal cycles more so than spatial variations.

Table 3. Comparison of Monthly Averaged Composite Sample Values vs. Monthly Slackwater Values $(\text{mg}\cdot 1^{-1})$.

	GOSHEN			PIG HILL		
Parameter	Auto Sampler	Slack	Δ	Auto Sampler	Slack	Δ
			MARCH			
S.S.	12.0	1.75	+ 10.25	23.5	11.25	+ 12.25
Chl.	1.0	1.35	- .35	2.3	6.35	- 4.05
Si.	.36	.28	+ .08	.99	1.2	- .21
TP	.04	.02	+ .02	.06	.04	+ .02
TKN	.46	.39	+ .07	.62	.53	+ .09
NH3F	.03	.01	+ .02	.08	.08	-
NO2NO3	.03	.01	+ .02	.04	.06	- .02
			APRIL			
S.S.	12.2	4.25	+ 7.25	19.9	6.0	+ 13.9
Chl.	3.32	2.9	+ .42	4.1	2.8	+ 1.3
Si.	.71	.63	+ .08	1.49	1.25	+ .24
TP	.05	.03	+ .02	.07	.04	+ .03
TKN	.61	.56	+ .05	.84	.68	+ .16
NH3F	.04	0	+ .04	.07	0.0	+ .07
NO2NO3	.02	0	+ .02	.03	0.0	+ .03
			MAY			
S.S.	16.2	9.5	+ 6.7	20.9	16.5	+ 4.1
Chl.	11.9	13.6	- 1.7	10.4	9.9	+ .5
Si.	.81	.94	- .13	1.13	1.2	- .07
TP	.08	.08	-	.09	.09	-
TKN	.81	.80	+ .01	.87	.89	- .02
NH3F	.01	0	+ .01	.02	0	+ .02
NO2NO3	0	0	-	.00	0	-

2.5 ASSESSMENT OF STORMWATER IMPACTS IN THE ESTUARY

A survey was conducted in the spring of 1980 to provide information on estuarine response to organic pulse loads caused by runoff. A series of nine high water slack surveys were conducted over a 20-day period (April 25 - May 14, 1980) to study a major rain event. Following a nine-day dry spell (previous spring dry spells lasted for only 3 days, see Figure 39), an average of 8 cm (3 inches) of rain fell in the watershed over several days, just after the spring application of agricultural fertilizers. Nineteen nutrient parameters were selected to detect enrichment; discrete water samples were taken at 11 estuarine and 4 freshwater stream sites. These results were compared against annual trends which had been obtained through semimonthly slackwater sampling during both wet and dry weather conditions.

Extremely low nutrient concentrations for silicates, total and orthophosphates, suspended solids, organic nitrogen, and nitrate+nitrite nitrogen were found in the estuarine mouth waters. Moderate nutrient enrichment levels were generally found upstream. Statistical comparisons between stations using Duncan's Multiple Range Test (see Section 2.1.4 for a description of the test) showed the mouth and headwater stations to be different (a= 0.05) in mean nutrient concentrations for 11 of the 19 analyzed parameters. Based on this distinction and the fact that salinity consistantly varied by 5 - 7 ppt, the river was divided into 2 groups, reflecting brackish (upstream) and downstream stations. These two groups were also compared with the two freshwater tributary stations in order to assess the estuarine responses to organic pulse loads resulting from runoff.

An initial dissolved oxygen sag was observed at the brackish stations following the first day of rain (Figure 40). Dissolved oxygen concentrations ranged from 4-5 mg/l representing a decrease in oxygen of about 2.2 mg/l from the seasonal mean of 6.8 mg/l. Rimer (1978) noted that in the Neuse River, NC, stormwater runoff generally depressed oxygen concentrations below the antecedent level by about 1 mg/l, and that oxygen depression lasted for less than a day. Two closely spaced storms could cause a decrease in dissolved oxygen of greater than 3 mg/l. Patterns in the Ware generally were similar, but the sag period lasted longer, with maximum sag occurring 24 hours following the last rainfall . Concentrations below 4 mg/l were measured in the marsh area (BS2, BS6); on May 10 and May 14, oxygen values less than 4.0 mg/l were present throughout the brackish region (W5, WFM1, WBS1, BS2, BS6). Dissolved oxygen curves fluctuated due to the numerous and often consecutive days of rain during the survey. This, plus the intermittent sampling limit the analysis of this data set.

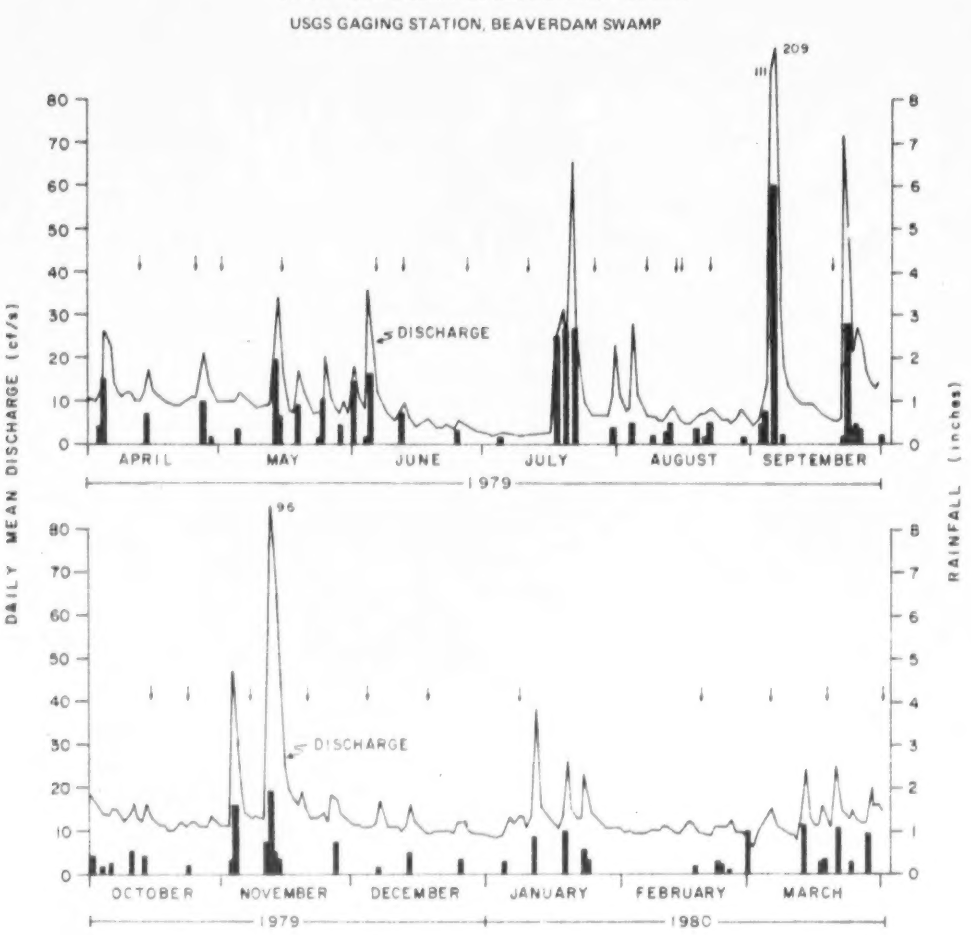
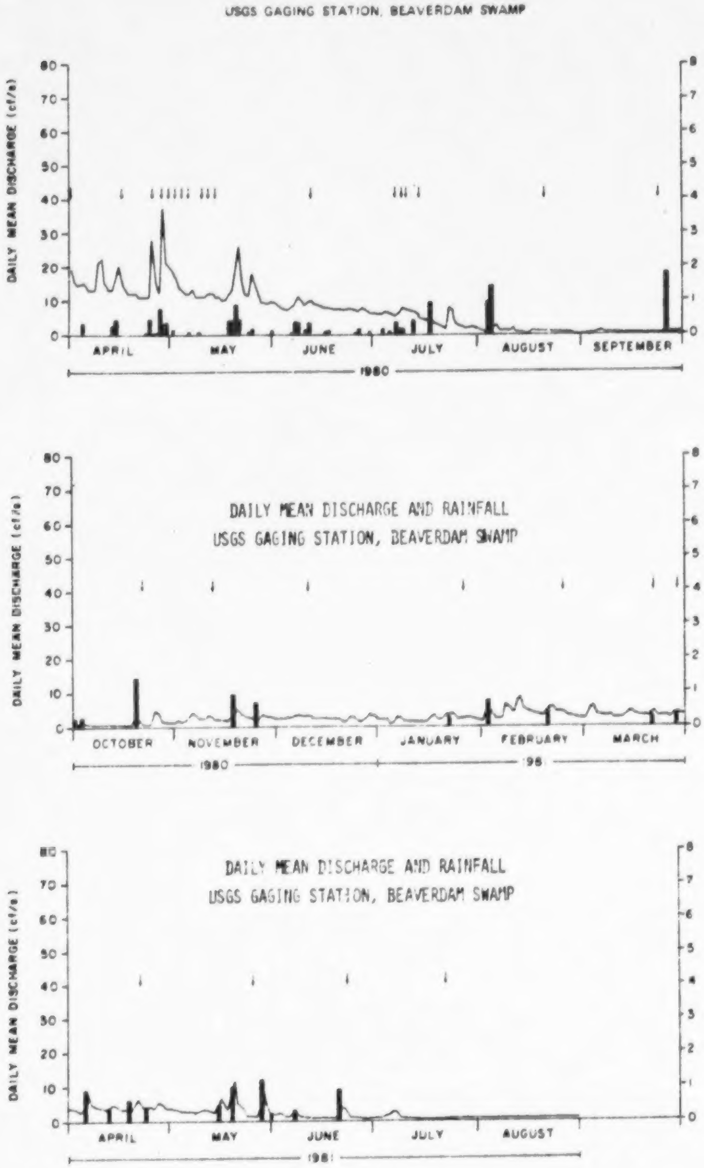


Figure 39. Rainfall and baseflow during the study period.


DAILY MEAN DISCHARGE (cfs) and RAINFALL (in.), USGS GAGING STATION, BEAVERDAM SWAMP

DAILY MEAN DISCHARGE AND RAINFALL USGS GAGING STATION, BEAVERDAM SWAMP

DAILY MEAN DISCHARGE AND RAINFALL USGS GAGING STATION, BEAVERDAM SWAMP

Figure 39 (continued). Rainfall and baseflow during the study period.

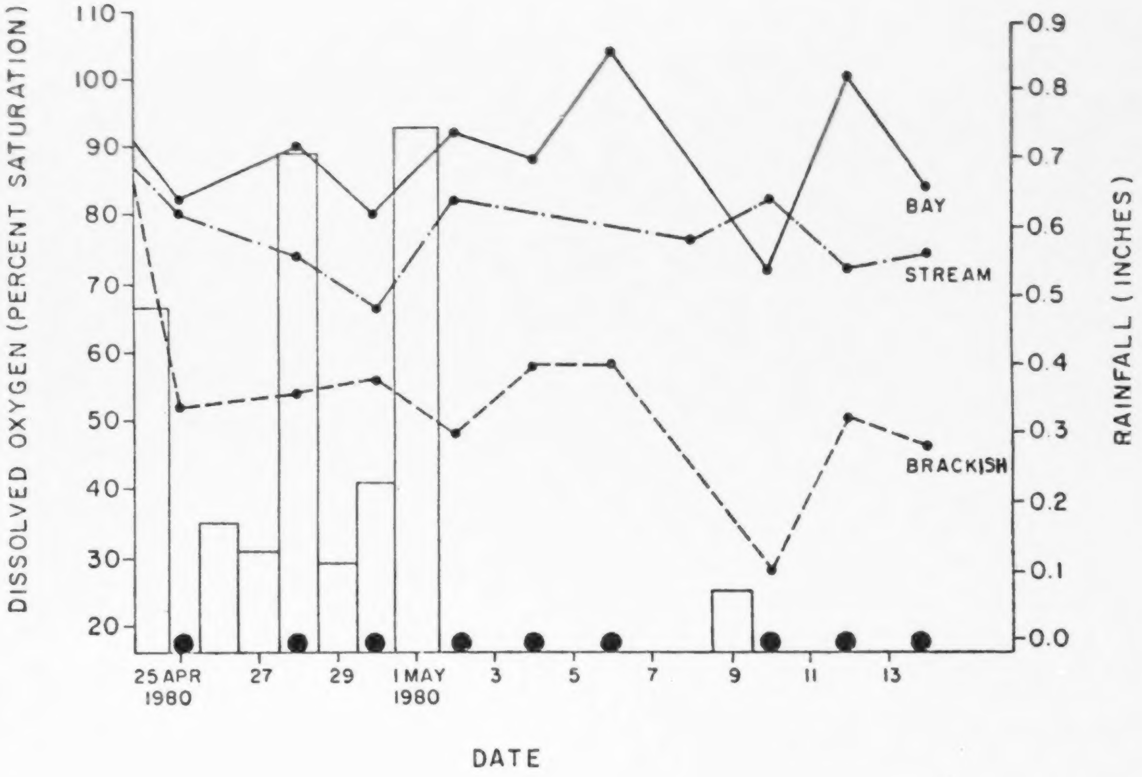


FIGURE 40. Relationship between dissolved osygen percent saturation and rainfall. Bar graphs reflect storm events in inches of rainfall. Circles represent sampling dates. Note initial DO sag within 24 hours of first rainfall. Maximum DO sag in the estuary occurred on May 10th.

Chlorophyll-a values were highest at the brackish stations 24 hr after the rain began (30.6 ug/l). With continuing rainfall and increased flow, chlorophyll-a values decreased, probably due to dilution, but remained well above the seasonal average of 4.5 ug/l. Chlorophyll-a values downstream did not show a response until 15 days later.

Increases in nitrate+nitrite nitrogen concentrations following the rain event were not detected at any site within the estuary (<0.01 mg/l for all stations). Loftus, et. al. (1972) reported similar values in the Rhode River and suggested that the turnover time for available nitrogen and/or the uptake rate of the phytoplankton must be extremely rapid to explain the low inorganic nitrogen levels. Notably, however, nitrate+nitrite nitrogen, total Kjeldahl nitrogen, total phosphorus, and chlorophyll-a values exceeded seasonal averages in the tributary stations.

Freshwater influence on the downstream stations were minimal: salinity varied 1.5 ppt during the 20 days, whereas upstream station salinities were lowest 4 days following the rainfall and averaged 4.4 ppt below seasonal averages at that time. Additionally, extreme stratification of the water column occurred at the upstream stations (WFM1, WBS1, BS2, and BS6) on May 2-6; an average salinity difference of 4 ppt was recorded between top and bottom samples (average depth = 1.2 m). Stratification was observed at W3 following the last day of rainfall (May 2), where a salinity difference of 1.3 ppt was recorded. This implies that during periods of increased freshwater flow, a two layer circulation system may exist. However the stratification is not ubiquitous throughout the estuary.

In summary, preliminary results indicate that the severity of impacts on the estuarine Ware River following a major storm event are slight, although they may present short term stress upon the system. Generally, nutrient concentrations within the estuary did not increase significantly above prestorm conditions for the 20 days of the rain survey. Deviations from seasonal mean values were slight, especially at the downstream stations. Larger changes, however, were measured upstream, where low oxygen concentrations (<5 mg/l) were found following the first 1.5 cm of rainfall.

From this it can be concluded that although high concentrations of nutrients may be present in the freshwater tributaries, the loadings are rarely detected in the estuary. These results may be explained by several hydrographic features of the Ware River basin. First, slow stream flushing times, as determined from a dry weather time-of-travel dye study, suggest that suspended solids and nutrients associated with particulate matter entering the streams from runoff may settle out before entering the estuary. Secondly, there is a larger ratio of receiving (estuarine) water to drainage area when compared to other larger coastal plain basins.

Finally, the effect of nutrient loadings may be most pronounced in the estuary when water temperatures are greatest. Higher temperatures not only tend to increase the release of phosphorus from the bed sediments, but such temperatures are also associated with increased biological activity.

2.6 WET vs. DRY HIGHWATER SLACK SURVEYS

The Ware River estuary generally has low nutrient concentrations. There are exceptions, however, especially during the summer months in the brackish regions were nutrient levels can become quite high.

Baseline slackwater nutrient concentrations were compared against surveys conducted during periods of elevated flow, based on data from the gaging station located on Beaverdam Swamp. Such comparisons may indicate whether increased nutrient concentrations are due to inputs from rain and NPS pollution or to the release of nutrients from the sediments or other factors.

Several slackwater surveys were selectively defined as "WET" or "DRY", based on level of saltwater intrusion and mean discharge data on the slackwater date (see Table 4). Note that salinities at W5, WFM1 and WBS1 averaged less than 12 ppt during "WET" slacks, but were greater than 12 ppt during "DRY" slacks.

The average annual percent dissolved oxygen saturation for the 3 brackish stations = 79%. "WET" slack saturation values generally fell below 70% (Figure 41). An exception to this was March 19, 1980, at which time the major spring phytoplankton bloom was evident thereby increasing the oxygen concentration in the water since sampling occurred around noon. On September 7, 1979, following Hurricane David, percent dissolved oxygen saturation fell to an unusual low of 57.4%; April 30, 1980 (during the major stormwater survey, refer to Section 5.1) also had especially low values, or 56%. Average values for "WET" and "DRY" periods were 71% and 77% respectively. Saturation trends were generally similar downstream as well, although values were slightly lower.

Chlorophyll-a data showed seasonal spring peaks and as such did not acutely relate to rainfall. The impacts of runoff appeared to produce an uneven chlorophyll-a response throughout the estuary which is to be expected since plankton growth is likely to lag behind rainfall events.

Slackwater runs were conducted before and after Hurricane David, a heavy fall storm in 1979 producing 12.7 cm (5 in) of rain. On September 4, 1979, suspended solids values in the brackish region averaged 14.7 mg/l. Following the storm, suspended solids in the same area more than doubled, averaging 38.3 mg/l (Figure 42). Stations W4 and W5 had the highest concentration of suspended solids on that date (71.0 and 63.0 mg/l respectively). It appears that suspended solids concentration in the estuary, may be dependent upon storm

Table 4. Comparison of Average Salinity and Daily Discharge Between "Wet" and "Dry" Slackwater Surveys.

	DRY SLACKS	USGS gaging station Beaverdam Swamp		WET SLACKS	USGS gage sta. Bvdm. Swamp
date	average salinity atW5, WFM1, WBS1	Daily discharge (cfs)	date	average salinity at W5, WFM1, WBS1	Daily discharge (cfs)
June 27, 1979	12.1	3.3	May 1, 1979	10.6	9.8
July 11, 1979	15.0	2.1	May 15, 1979	5.1	16.0
Aug. 22, 1979	13.6	8.2	June 6, 1979	9.4	12.0
Sept. 4, 1979	14.2	13.0	Sept. 7, 1979	9.0	33.0
Dec. 18, 1979	12.6	9.6	Nov. 20, 1979	11.2	15.0
May 12, 1980	13.1	11.0	March 9, 1980	10.2	13.0
June 12, 1980	14.7	10.0	April 30, 1980	8.9	20.0

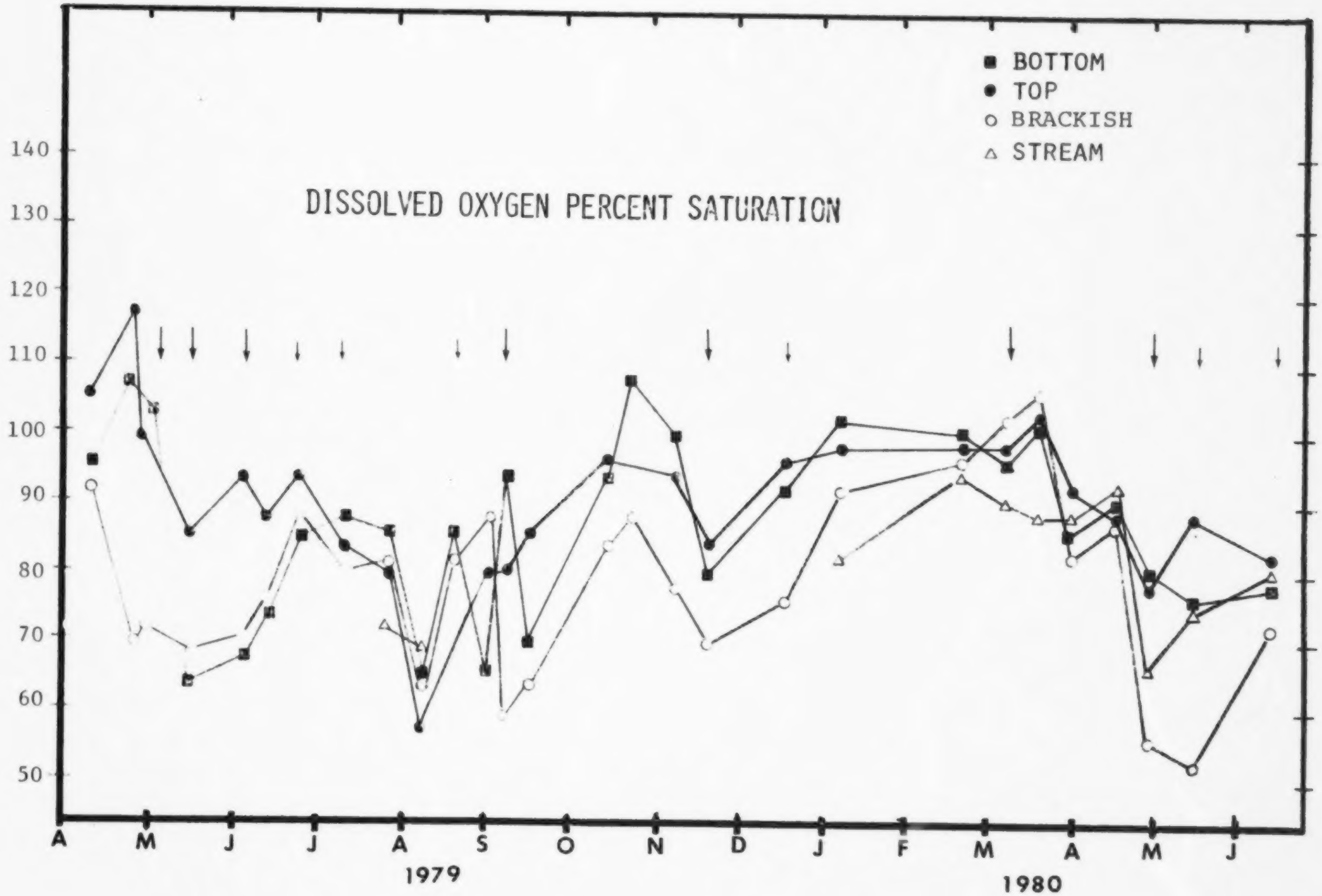


FIGURE 41. Dissolved oxygen percent saturation at estuarine and freshwater stream stations, April 1979 - June 1980. Large arrows indicate "Wet" highwater slack surveys; small arrows represent "Dry" highwater slack surveys.

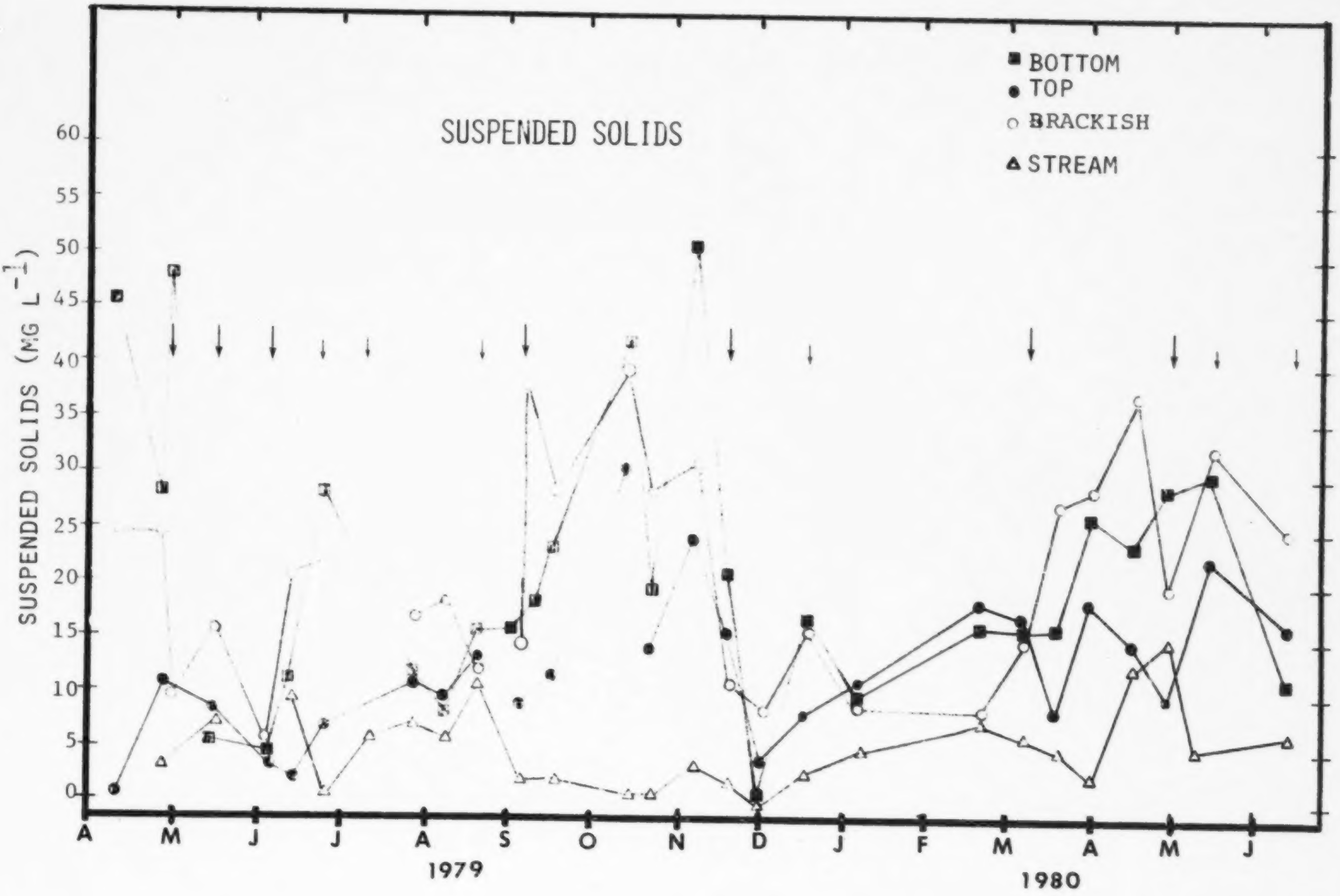


FIGURE 42. Suspended solids concentrations at estuarine and freshwater stream sites, April 1979 - June 1980. Large arrows indicate "Wet" highwater slack surveys; small arrows represent "Dry" highwater slack surveys.

intensity since there was no obvious relation to discharge, nor to season.

Total phosphate, which is oftentimes associated with suspended solids, was highest in the streams and showed no obvious relation to discharge. Orthophosphates were also of greatest concentration in the freshwater tributaries, but did appear to show a direct response to rain (Figure 43); rather than increase due to rainfall, levels would drop reflecting dilution from increased baseflow.

Levels of nitrite+nitrate nitrogen were an order of magnitude greater in the freshwater tributaries than in the brackish regions. Values were often less than 0.01 mg/l (below detection limit) towards the mouth of the estuary. Nitrite+nitrate nitrogen concentrations showed a direct response to storms of >1.3 cm (0.5 in) total rainfall within 72 hours (Figure 44), although stormwater responses were not evident in the brackish area during the winter and early spring months, or times of saturated soils and maximum runoff (dilution) per cm of rain.

Biological oxygen demand in the brackish region generally increased in response to rainfall coincident with increased inorganic nitrogen and phosphorus inputs to the estuary. Responses were not discernable downstream for this parameter.

Rainfall and runoff may exert impacts upon receiving waters which are independent from seasonal tendencies through increased nutrient loading to the estuary. The extent, duration and severity of NPS pollution may vary greatly dependent upon amount and intensity of rainfall and time of year (temperature and vegetation influences). Generally responses in the estuary are short-lived; the increased nutrient loadings are offset by dilution upon entering the broad reaches of the estuary.

Results from the trend data also suggest that increased nutrient concentrations in the spring and fall are probably due to runoff contributions, and inputs in the form of marsh debris. During the summer, or times of low flow and high temperature, nutrient cycling and release from the sediments may be the primary factor controlling nutrient levels in the estuary.

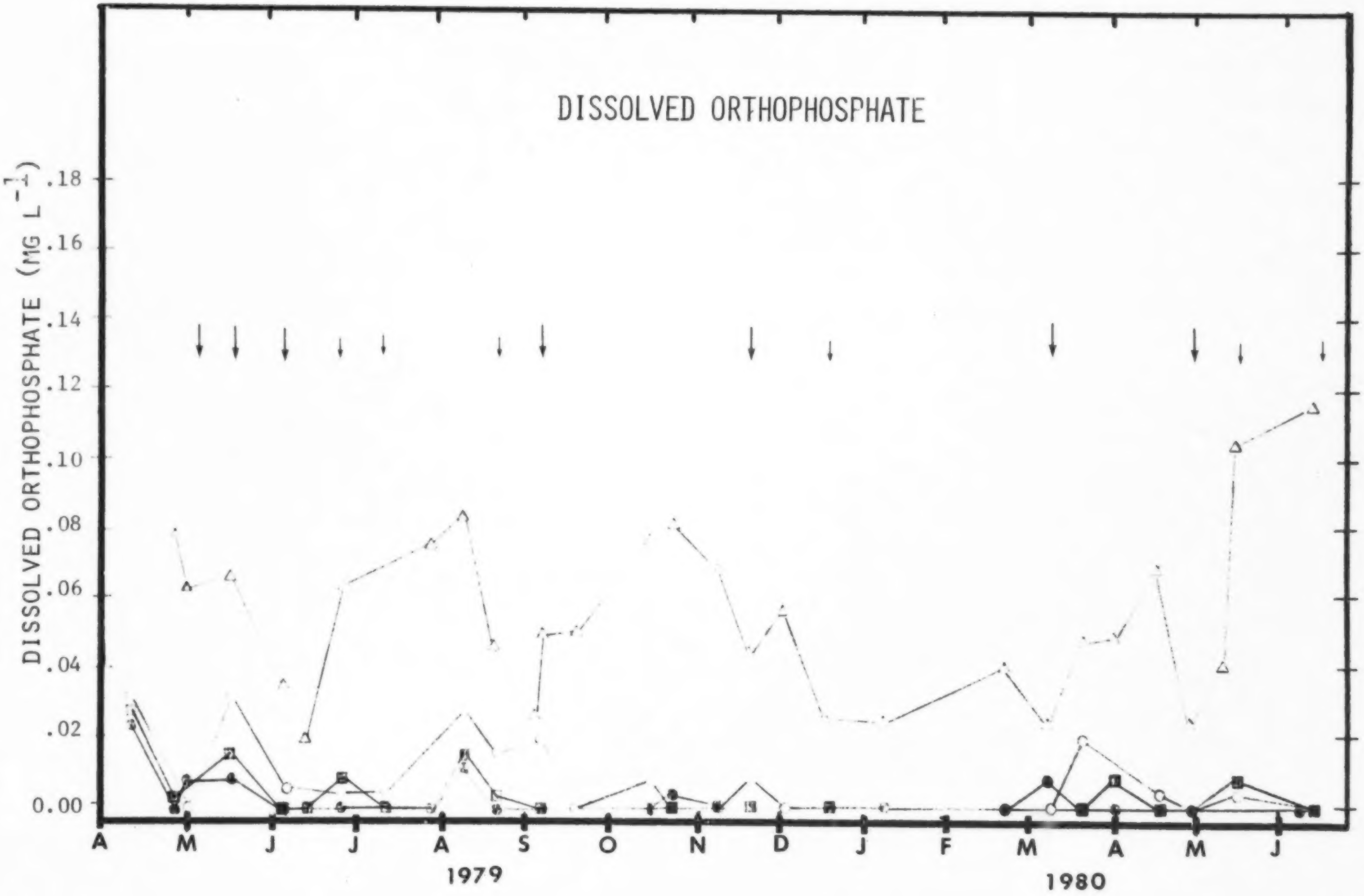


FIGURE 43. Dissolved orthophosphate concentrations at estuarine and freshwater stream stations, April 1979 - June 1980. Large arrows indicate "Wet" highwater slack surveys; small arrows represent "Dry" highwater slack surveys.

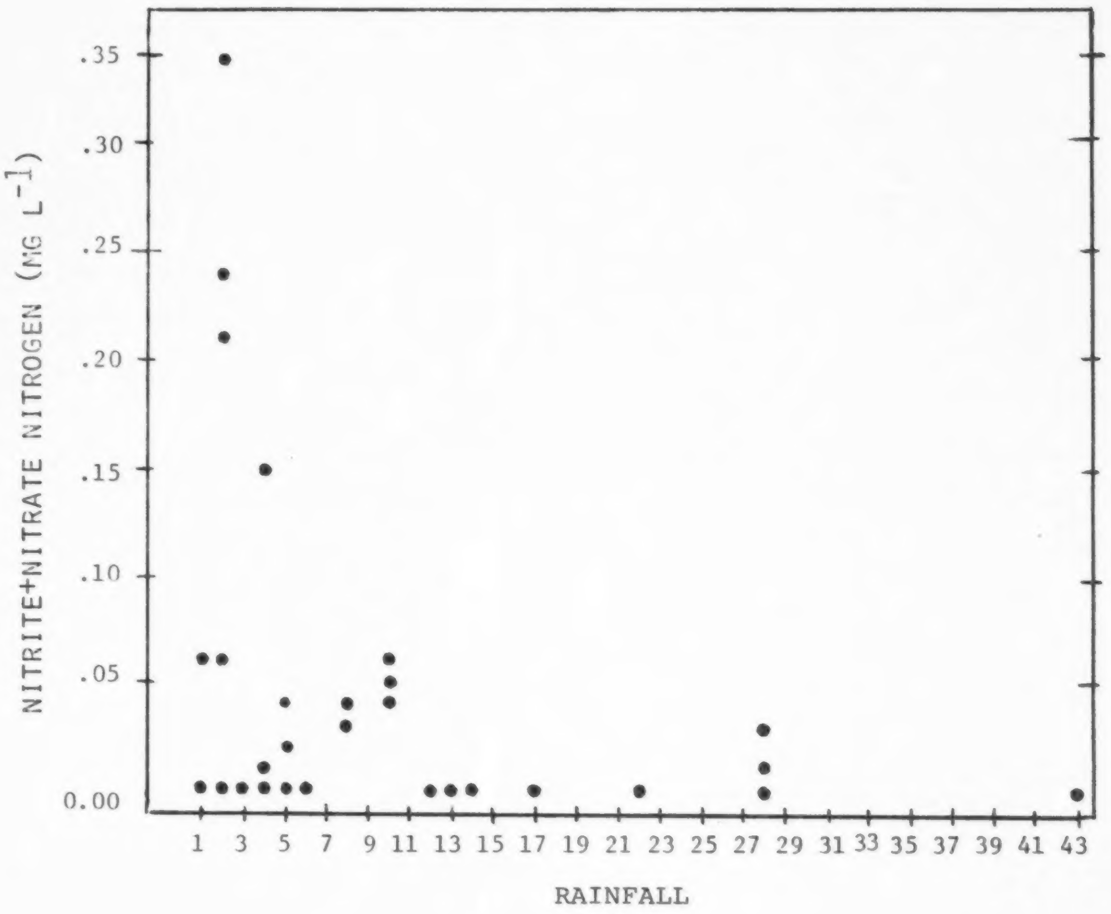


FIGURE 44. Relationship of nitrite+nitrate nitrogen concentration to rainfall (cm) in the upper estuary.

2.7 OTHER TOPICS

Several topics which have been investigated did not fall into any of the preceeding categories. These include discussion of the transition zone and the turbidity maximum.

2.7.1 TRANSITION ZONE

When the Ware project was initiated, little enviromental data was available for the design of the field program. It was felt necessary to differentiate between the two freshwater tributaries, but shallow mud flats made it difficult to proceed upriver much beyond Warehouse Landing. Therefore, the two most upriver stations in the estuary were located in the two tributaries just upriver of the confluence. At that time it was anticipated that the salinity at these stations would be very low, since they are about two-thirds of the way upriver from the mouth to the limit of tidal influence. Field data have shown that this is not the case. In addition, nutrient concentrations at these locations were found to be higher than in the lower estuary. Therefore it was decided that this region merited further attention.

The reaches of the tributaries between Warehouse Landing and the upper limit of tidal oscillations include extensive marshes. Several preliminary surveys into the marsh or oligohaline (0 to 5 ppt) region revealed large fluctuations in the degree of saltwater intrusion and high levels of total phosphorus and dissolved silicates.

On April 17, 1980 two stations (BS2 and BS6, see Appendix A-1) in the marshes of Beaverdam Swamp were occupied from 0900 to 1300, or from about two hours befoe high water slack until two hours after HWS. Boats were anchored at the stations, hand-held current meters (Byrne and Boon, 1973) were employed and water samples were collected for dissolved nutrient analyses. Velocity readings, staff height, dissolved oxygen and salinity were measured every 15 minutes; nutrients were sampled hourly.

The survey revealed several interesting features. Maximum currents observed at BS2 and BS6 were 0.31 and 0.44 m/sec respectively, and occurred approximately 45 minutes after HWS (Figure 45). The velocity was higher at BS6 presumably because the channel is narrower and deeper. Temperatures rose from 9.5 C (0900 hours) to 13.0 C during the study.

Dissolved oxygen ranged from a morning low of 6.6 to 8.6 mg/l just before noon at BS2, and 7.2 to 8.9 mg/l at BS6.

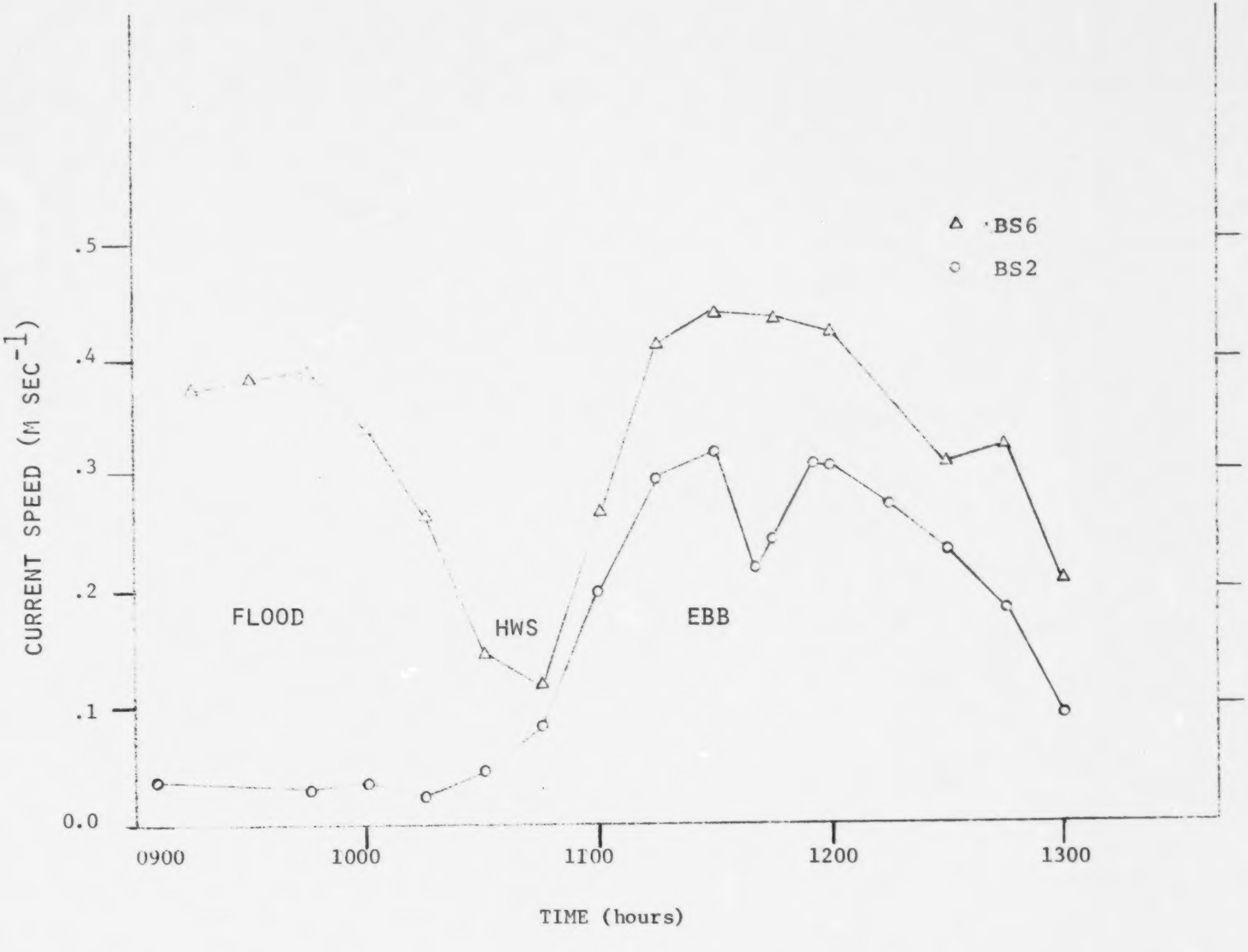


FIGURE 45. Current speeds (m sec^{-1}) at stations BS2 and BS6, April 16, 1980.

Salinity ranged from 11.5 to 12.0 ppt (top-bottom) at HWS to half those values (5.2 - 6.3 ppt) two hours later at BS2, representing a salinity variation of 6.3 ppt. Station BS6 varied from 8.5 (both top and bottom) at HWS to 0.4 ppt during the same time period. This showed a strong salinity gradient present in the marsh; fluctuations in the mainstem of the estuary over similar time periods were about 4 ppt in the brackish region and less than 2 ppt near the mouth.

Concentrations of suspended solids, silicates and nitrite+nitrate nitrogen were high in the oligohaline reaches of the Ware River, as shown in Figures 46-48. Nutrient concentrations were lowest at high water slack, indicating that these waters are enriched relative to the Bay-derived waters near the mouth. The elevated nutrient levels may be asssociated with groundwater and surface runoff or they may represent an export from the marsh.

Chlorophyll-a values similarly were greater in the marsh than at WBS1. Total phosphorus values decreased from BS6 to BS2, perhaps as a result of adsorption and settling. More baseline information is needed on the marsh area before export/import conclusions can be drawn. Nonetheless, in the narrow marshes, nutrient levels fluctuate more rapidly and to a larger extent than in the broader shallow reaches at WBS1 and WFM1 near the confluence. Because times of maximum currents occur within less than an hour before and after HWS, it becomes imperative to stay close to slack time for such studies, if that is the basis upon which data is to be intercompared.

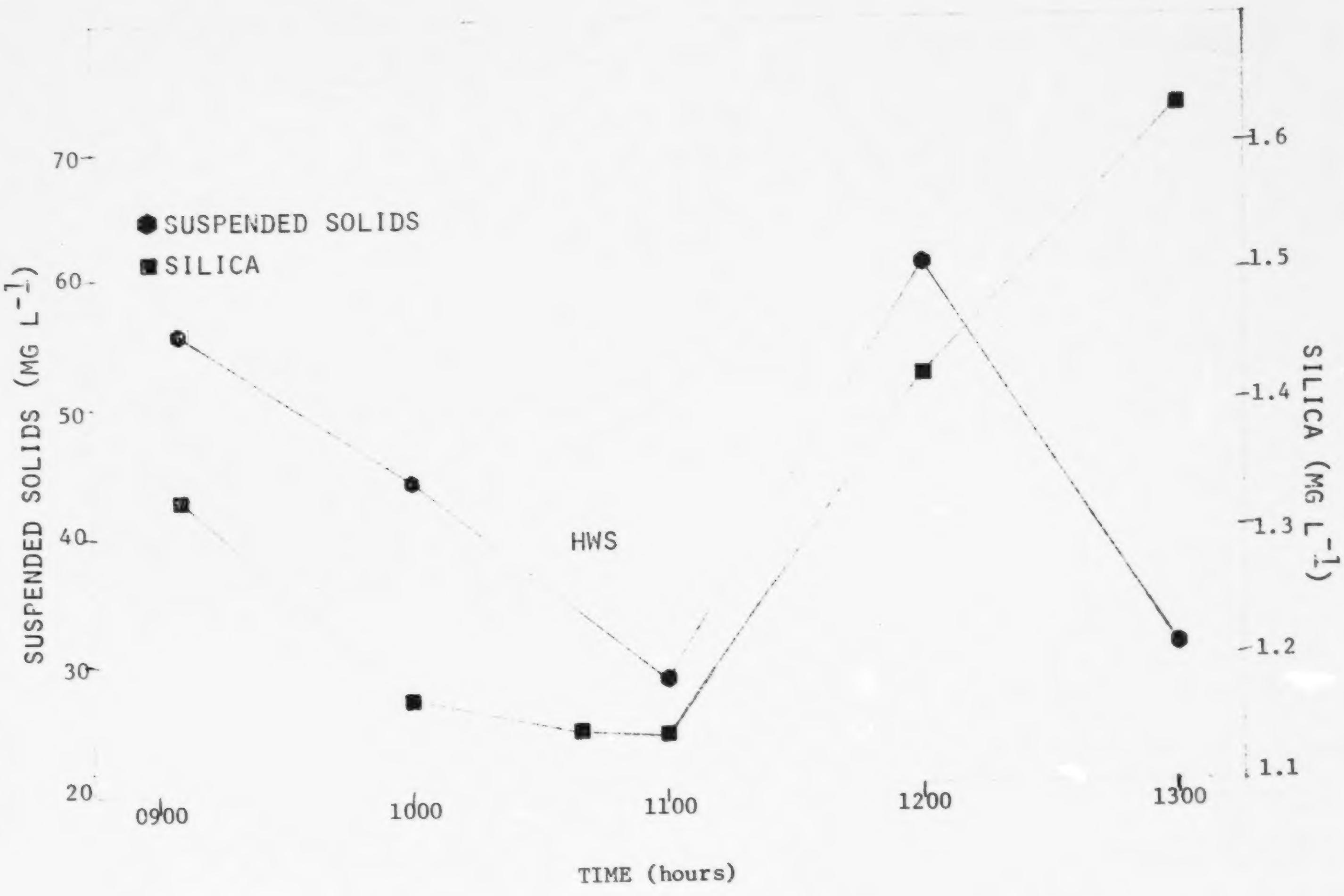


FIGURE 46. Concentrations of suspended solids and silica at station BS2, April 16, 1980.

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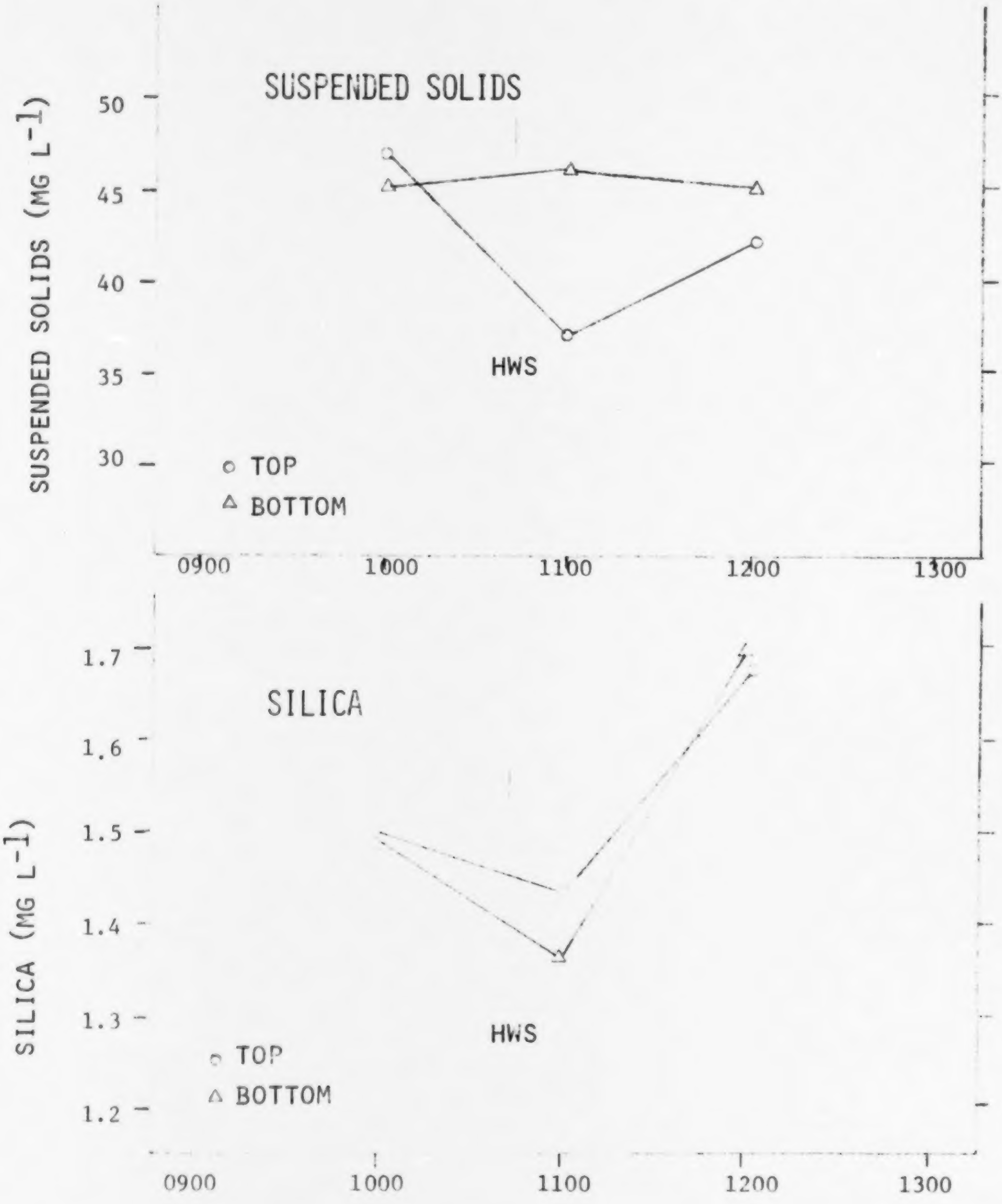

FIGURES 47 and 48. Concentrations of suspended solids and silica at station BS6, April 16, 1980. Top and bottom samples were taken.

2.7.2 TURBIDITY MAXIMUM

Alot of attention is given to the saltwater/freshwater interface region in an estuary since many dissolved forms of nutrients tend to flocculate upon encountering saltwater, whether due to physical mixing phenomena or chemical reaction. This creates an environment which is generally high in turbidity, nutrient rich, and tends to contain higher concentrations of organic matter than those present in either fresh or salt water.

Such turbidity maxima have been observed in estuaries of varying size, shape, and dynamic character; both well-mixed and stratified (Nichols, 1972). As a part of the second year plan to emphasize study in the upstream areas, an initial trip was scheduled into the tidal reaches of Beaverdam Swamp to determine if a turbidity maximum might be present. On November 3, 1980, a clear day with good water column visibility, a Turner Design flow-through fluorometer was used to get a rough measure of turbidity *in situ*. Sampling was planned around low water slack. Monitoring began upstream of WBS1 (salinity: 18.8% ppt) and ended downstream of BS8 (0.3 ppt), when background recordings had returned to the baseline.

Results showed turbidity to increase steadily with distance upstream and peaked at approximately rivermile 7.5, with a recording five times background level.

Chemical and physical data tend to lend support to the presence of a turbidity maximum as well: station BS6 contained the highest mean suspended solids concentration of any station in the saltwater region (X=28.5 mg/l). Concentrations tended to increase with distance upstream but then declined, similar to the fluorometric findings. Chlorophyll-a concentrations followed the same trend as suspended solids (Table 5).

Salinity was unusually high at BS6 (10.8 ppt), not what would be considered indicitive of a turbidity maximum. However previous work (see Section 2.7.1) showed a strong longitudinal salinity gradient present in the marsh. Concentrations were found to change as much as 3-4 ppt per km in the marsh region during LWS (Intensive Surveys 1980, 1981). Stations BS6 and BS8 are roughly 4 km apart therefore the turbidity maximum could very likely occur at some place between the 2 stations and presumably shifts with season and fresh water flow.

TABLE 5. Chemical Evidence for a Turbidity Maximum.

Station	Rivermile	$\bar{X}$ SS	$\bar{X}$ Chl-a	$\bar{X}$ Sal
WBS1	5.9	21.0	12.6	18.8
BS2	6.4	24.7	12.4	13.6
BS6	6.8	28.5	17.3	10.8
BS8	9.0	13.8	12.9	0.3

2.7.3 ONGOING STUDIES

One of the primary goals of the Ware River Intensive Watershed Study has been to observe the impacts of stormwater runoff on estuarine water quality. Another important aspect of the problem is bacterial fluctuations due to runoff since the Ware River estuary includes several productive shellfish areas. A portion of the shellfish waters are condemmed for direct harvesting because of the wastewater discharge from Gloucester Court House. A small study is being conducted to define both the dry weather and wet weather distributions of bacteriological indicators in the upper portions of the Ware River estuary. The work is being conducted simultaneously with an ongoing project in the Ware River dealing with fecal coliform and pathogen (Salmonella sp.) survival. The combined results will assist managers of shellfish resources by documenting the temporal and spatial extent of bacterial contamination due to wastewater discharges and stormwater runoff during dry and wet weather conditions. The studies will also provide valuable information for use in mathematical modeling of stormwater runoff.

Methodology

Study sites consist of four locations previously characterized with respect to nutrient and physical parameters during the first two years of the watershed study. Two sites have been located in the tributaries, FM2 and BS8, which drain the upper reaches of the Ware River basin. The other two sites are located ca. 0.7 and 2 miles downstream from the confluences of the tributaries (Stations W5 and W4).

Up to five surveys will be conducted to establish background trends in estuarine water quality at each site during periods of dry weather, i.e. no rain on each of three preceding days. Surface water (0.5 m in depth) will be sampled daily during slack water before flood for three consecutive days (weather permitting). Water samples will be analyzed using a five-tube most- probable-number technique according to the Medium A-1 procedure, modified to include a resuscitation step for the recovery of debilitated fecal coliforms. The modified A-1 test as approved by the National Shellfish Sanitation Program was selected because it allows for a rapid enumeration (within 24 hours) of fecal coliforms. Also, a maximum of five storm events resulting in rainfall of 0.5 in. or greater will be monitored as explained above to describe the wet weather response.

In addition to bacteriological investigations, samples will be analyzed for various nutrient and physical parameters. Specifically, dissolved oxygen, salinity, temperature, suspended solids, total phosphorus, and total nitrogen (measured as organic nitrogen, ammonia-nitrogen and nitrite+nitrate nitrogen) will be analyzed.

Data will be analyzed, interpreted and submitted in report form to both State Water Board and Bureau of Shellfish Sanitation upon completion.

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APPENDIX A

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TABLE A-1. DESCRIPTION OF SLACKWATER SAMPLING STATIONS

A fortnightly high slackwater sampling program on the Ware River estuary was initiated on April 11, 1979 and continued until May 14, 1980 when the frequency was reduced to once per month. The purpose of these same slack surveys was to delineate seasonal trends in water quality. During the surveys grab samples were taken at 16 distinct locations, including four freshwater stream sites and twelve stations in the estuary. A brief description of the sampling sites follows. Numbers in parentheses indicate how sample bottles were labelled.

ESTUARINE STATIONS

<table>
<tr><th>Station</th><th>Latitude</th><th>Longitude</th><th>Water Depth at MHW</th><th>River Mile</th></tr>
<tr><td>W1</td><td>37 21' 20"</td><td>76 24' 52"</td><td>8.5 m</td><td>0.00</td></tr>
<tr><td></td><td colspan="4">Located 50' off north side of black and white channel marker "M21". Average depth is 8 metres. Samples are taken one metre from the surface (W1T) and one meter from the bottom (W1B).</td></tr>
<tr><td>W2</td><td>37 22' 09"</td><td>76 26' 21"</td><td>5.0 m</td><td>1.4</td></tr>
<tr><td></td><td colspan="4">Located 50' off north side of green marker "3". Average depth is 5 metres. Samples are taken one metre from the surface (W2T) and one metre from the bottom (W2B).</td></tr>
<tr><td>W3</td><td>37 22' 08"</td><td>76 27' 21"</td><td>5.0 m</td><td>2.4</td></tr>
<tr><td></td><td colspan="4">At the intersection of two lines: (W3T and W3B)
1) Line up 2 pines on Windmill Point, also passing through white house at mouth of Wilson Creek.
2) Red marker "6", duck blind, Jarvis Point going to landward end of pier.</td></tr>
<tr><td>W4</td><td>37 23' 16"</td><td>76 27' 28"</td><td>5.0 m</td><td>3.7</td></tr>
<tr><td></td><td colspan="4">Located 15' off south side of green marker "9". Average depth is 5 metres. All samples taken at mid-depth (W4).</td></tr>
<tr><td>W5</td><td>37 23' 46"</td><td>76 28' 45"</td><td>2 m</td><td>5.0</td></tr>
<tr><td></td><td colspan="4">Located 15' off south side of red marker "12". Average depth is 2 metres. All samples taken at mid-depth (W5).</td></tr>
<tr><td>WWC 1</td><td>37 21' 55"</td><td>76 28' 15"</td><td>2 m</td><td>3.2</td></tr>
<tr><td></td><td colspan="4">Located in the center of Wilson's Creek channel, slightly upstream from third day marker, siting off pier on point of land on left and and house on point of land on right. Average depth is 2 metres. All samples taken at mid-depth (WWC1).</td></tr>
<tr><td>WWC 2</td><td>37 21' 50"</td><td>76 28' 45"</td><td>2 m</td><td>3.6</td></tr>
<tr><td></td><td colspan="4">Located at confluence of the 2 tributaries in Wilson's Creek, siting off pier on left and point of land on right. Average depth is 2 metres. All samples are taken at mid-depth (WWC2).</td></tr>
</table>

TABLE A-1 (Continued)

<table>
<tr><th>Station</th><th>Latitude</th><th>Longitude</th><th>Water Depth at MHW</th><th>River Mile</th></tr>
<tr><td>WFM 1</td><td>37 24' 04"</td><td>76 29' 35"</td><td>1.2 m</td><td>5.6</td></tr>
<tr><td colspan="5">Located in center of stream, siting off northernmost point on Perrin Point and southern tip of Warehouse Landing. Average depth is 1.2 metres. All samples are taken at mid-depth (WFM1).</td></tr>
<tr><td>WBS 1</td><td>37 24' 37"</td><td>76 20' 30"</td><td>1.2 m</td><td>5.9</td></tr>
<tr><td colspan="5">Located in center of stream, siting off third cusp upstream from Warehouse Landing on left and off second point of land on right. All samples taken at mid-depth (WBS1).</td></tr>
<tr><td>BS 2</td><td>37 24' 50"</td><td>76 29' 35"</td><td>1.5 m</td><td>6.35</td></tr>
<tr><td colspan="5">Located at mouth of marsh creek about 50' north of point which divides wide section of Ware River with tidal flats from the narrow marsh creek. All samples taken at mid-depth and in the middle of the channel (WBS2).</td></tr>
<tr><td>BS 6</td><td>37 24' 48"</td><td>76 29' 50"</td><td>3 m</td><td>6.8</td></tr>
<tr><td colspan="5">Located in the straight section of the marsh creek approximately one half mile upstream of WBS 2. All samples taken at mid-depth and mid-channel (WBS6).</td></tr>
<tr><td>BS 8</td><td>37 24'50"</td><td>76 30' 45"</td><td>0.6 m</td><td>9.0</td></tr>
<tr><td colspan="5">Located at the head of the marsh creek where it becomes hardwood swamp. All samples taken at mid-depth and mid-channel (WBS8).</td></tr>
<tr><td>FM 2</td><td>37 24' 10"</td><td>76 30' 30"</td><td>1 m</td><td>7.4</td></tr>
<tr><td colspan="5">Located 3400' downstream from Route 17 directly underneath power lines that stretch from Deacon's Neck across Fox Mill Run. All samples taken at mid-depth and mid-channel (WFM2).</td></tr>
</table>

TABLE A-1. (Continued)

NONPOINT SOURCE AND FRESHWATER STREAM STATIONS

Station	Latitutde	Longitude
STR 1	37 22' 16"	76 30' 50"
NPS 2	37 23' 40"	76 29' 40"
STR 3	37 24' 32"	76 31' 06"
STR 4	37 24' 52"	76 31' 08"
NPS 5	37 24' 30"	76 29' 10"
STR 6	37 25' 38"	76 29' 48"
NPS 7	37 27' 52"	76 33' 25"
NPS 8	37 26' 50"	76 35' 30"
STR 9	37 25' 30"	76 31' 45"
STR 10	37 24' 35"	76 31' 55"
STR 11	37 28' 14"	76 33' 48"

TABLE A-2. DESCRIPTION OF 1979 INTENSIVE SURVEY STATIONS

During the intensive survey of August 14-15, 1979 all slackwater stations were occupied. Additional stations described below, were manned along the transects in the broader reaches of the estuary (also see Figure A-1).

Station	Latitude	Longitude	Water Depth at MHW
W1N	37 21' 46"	76 24' 37"	2.0 m

(Northern shoreline). Located at intersection of one line passing through Ware Neck Point and channel marker "M21", and another line passing through the two duck blinds along the shore. Average depth is 3.2 metres. Samples are taken at mid-depth.

W1S	37 21' 00"	76 25' 10"	3.2 m

(Southern shoreline). Located 400 yards off shoreline, facing middle inlet (of three) which appears as a small, sandy beach area, and on line with Ware River Point and a channel marker on the SE horizon. Average depth is 2 metres. All samples are taken at mid-depth.

W2N	37 22' 45"	76 25' 54"	3.5 m

(Northern shoreline). Samples taken 200 yards off first dock to the west of the inlet where the Ware River Yacht Club is located, and along a line with the green "3" channel marker. All samples are taken at mid-depth; average depth is 3 metres.

W2S	37 21' 57"	76 26' 29"	3.0 m

(Southern shoreline). Located at intersection of transect line passing from the white house on the northern shore, through green "3" channel marker, ending at the clear beach area at the edge of the stand of trees on the shouthern shore, and on line with the duck blinds due west of the transect. Average depth is 3.5 metres. All samples are taken at mid-depth.

W3N	37 22' 26"	76 27' 17"	1.7 m

Located in between 2 duck blinds found along the tansect between station W3 and the small island in mid-river. Sample 50 yards off the north side of the southern blind. Average depth is 1.7 metres. All samples taken at mid-depth.

TABLE A-3. WARE RIVER SLACKWATER SURVEY DATES

Sampling dates and times for highwater slack surveys are listed below.

Sample date				Sample time
April	11	1979		0900 - 1130
	25	1979		0830 - 1030
May	01	1979		1100 - [illegible]*
	15	1979		1415 - 1600*
June	06	1979		0645 - 0845*
	12	1979		1020 - 1230*
	27	1979		1020 - 1215*
July	11	1979		1000 - 1200*
	26	1979		[illegible] - 1145*
August	08	1979		0915 - 1110*
	14	1979		1500 - 1600*
	15	1979		[illegible] - [illegible]*
	22	1979		0900 - 1030*
September	04	1979		0950 - 1125*
	07	1979		0930 - 1050*
	19	1979		0815 - 0945*
October	15	1979		[illegible] - 1905*
	23	1979		[illegible] - [illegible]*
November	07	1979		[illegible] - 1220
	20	1979		[illegible] - 1225
December	04	1979		0915 - 1055
	18	1979		[illegible] - 1030
January	08	1980		[illegible] - 1400
February	19	1980		1052 - 1230
March	06	1980		1110 - 1250
	19	1980		1110 - 1230
April	01	1980		0835 - 1020
	16	1980		0923 - 1110
	25	1980	R	0530 - 0710*
	28	1980	R	0915 - 1100*
	30	1980		0915 - 1200*
May	02	1980	R	1010 - 1130*
	04	1980	R	1115 - 1230*
	06	1980	R	1320 - 1430*
	10	1980	R	0615 - 0730*
	12	1980	R	0745 - 0850*
	14	1980		0915 - 1045*

R Stormwater Impact Survey

* Daylight Savings Time

Table A-3 (continued).
Ware River Slackwater Survey Data

Sample date				Sample time
June	12	1980		0845 - 1045*
July	7	1980		0440 - 0715*
July	9	1980	Summer Intensive	
July	10	1980		
July	14	1980		0935 - 1225*
July	31	1980		1200 - 1330*
August	20	1980		1645 - 1845*
September	23	1980		0745 - 1030*
October	22	1980		0830 - 1030*
November	13	1980		1100 - 1230
December	11	1980		1045 - 1250
January	26	1981		1245 - 1430
Febuary	25	1981		1200 - 1340
March	24	1981		1030 - 1215
March	25	1981	Spring Intensive	
March	26	1981		
March	31	1981		1600 - 1830
April	22	1981		1000 - 1130
May	26	1981		1430 - 1600*
June	23	1981		1330 - 1515*
July	22	1981		1420 - 1540*

Table A-4. Description of Events Sampled at Each Station.

Station	Event Sampled
W1S	I1
W1	I1, S1, R1,
W1N	I1
W2N	I1
W2	I1, S1, I2 S2
W2S	I1
W3	I1, S1, R1 I3, S2
W3N	I1
W4	I1, S1, R1, I2, I3, S2
W5	I1, S1, R1, I2, I3, S2
WWC1	I1, S1
WWC2	I1, S1, R1, I2, I3, S2
WFM1	I1, S1, R1, I2, I3, S2
WBS1	I1, S1, R1, I2, I3, S2
WBS2	R1
WBS6	R1, I2
WBS8	I2, I3, S2
WFM2	I2, I3, S2

Key:

S1= Highwater Slack surveys, 1st year
I1= 1st Intensive survey, August 14-15, 1979
R1= 1st Rainevent, April-May, 1980
S2= Highwater Slack surveys, 2nd year
I2= 2nd Intensive, July 9-10, 1980
I3= 3rd Intensive, March 25-26, 1981

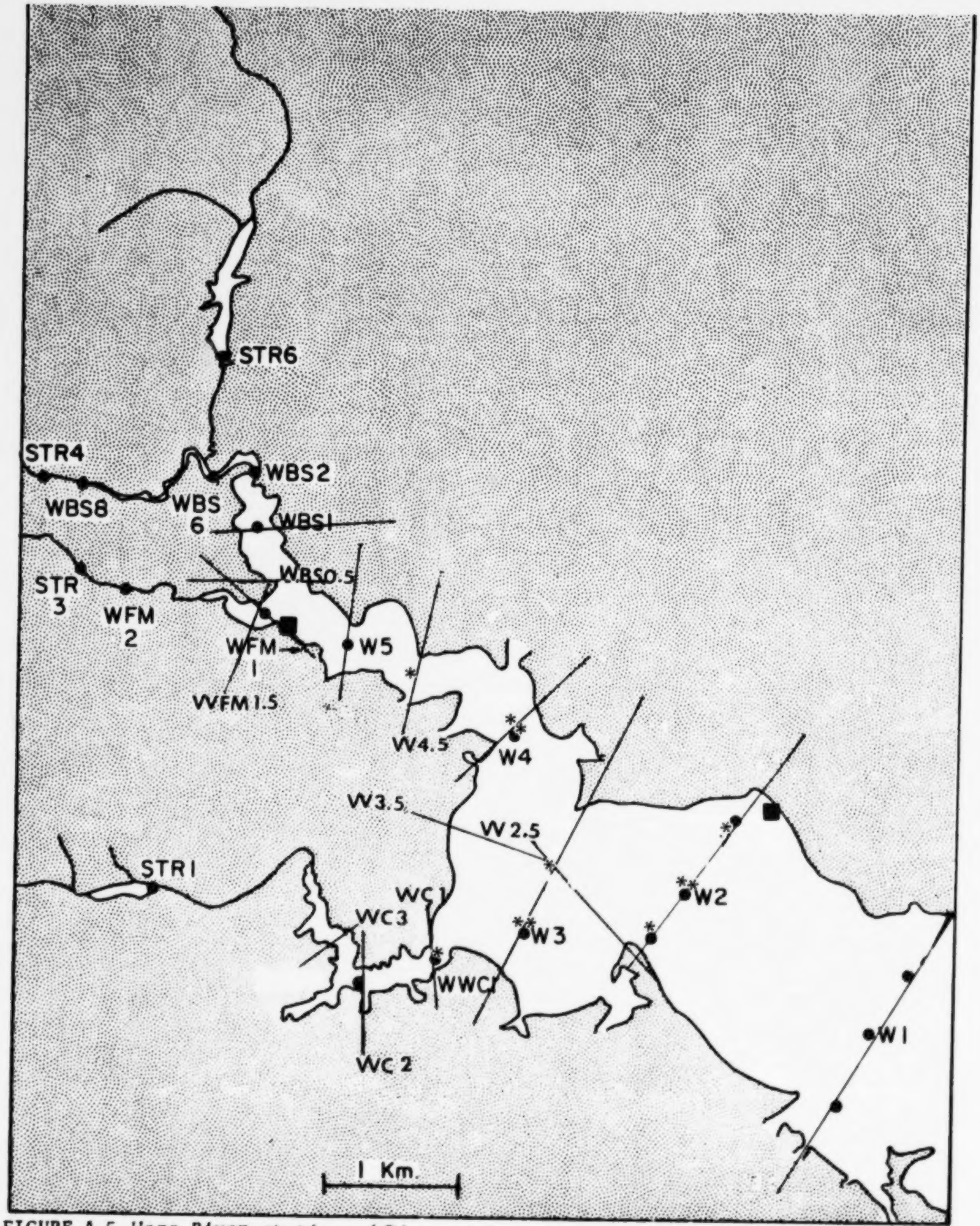
STR6
STR4
WBS2
WBS8
WBS 6
WBS1
STR 3
WFM 2
WBS0.5
WFM 1
W5
WFM1.5
W4.5
W4
W3.5
W2.5
STR1
WC1
WC3
W2
W3
WWC1
W1
WC 2
1 Km.

FIGURE 4-5 Ware River stations (●), and locations of bathymetric transects (—), tide gauges (■), and current meters (*), 1979-1981.

Table A-6. WARE RIVER BATHYMETRIC INFORMATION

Transect	Area at MTL (M^2)	Rivermile
W1	8304.11	0.0
W2	8096.98	1.4
W2.5	4976.63	1.9
W3	3466.67	2.4
WC1	344.75	3.2
WC2	257.19	3.6
WC3	163.05	3.9
W3.5	2996.35	3.2
W4	1236.38	3.7
W4.5	988.74	4.4
W5	635.94	5.0
WFM1	123.88	5.6
WFM1.5	138.86	5.7
WBS0.5	351.17	5.6
WBS1	214.62	5.9